Frontiers of Network Science
Fall 2023

Class 2: Graph Theory
(Chapter 2 in Textbook)

Boleslaw Szymanski

based on slides by Albert-László Barabási & Roberta Sinatra

Topic Choices for Grad Projects

1. Quantifying the future lethality of terror organizations, Yang Yang, Adam R Pah, Brian Uzzi, *Proc. the Nat. Acad. of Sci.* **116**(43):21463–21468 (2019)

2. The universal decay of collective memory and attention, C. Candia, C. Jara-Figueroa, C. Rodriguez-Sickert, A.-L. Barabási, C. A Hidalgo, *Nature Human Behaviour*, **3**:82–91 (2019)

3. Quantifying reputation and success in art, Samuel P. Fraiberger, Roberta Sinatra, Magnus Resch, Christoph Riedl, Albert-László Barabási, *Science,* **362**:825–829 (2018)

4. Experimental evidence for tipping points in social convention, Damon Centola, Joshua Becker, Devon Brackbill, Andrea Baronchelli, *Science*, **360**:1116–1119 (2018)

5. Scientific prize network predicts who pushes the boundaries of science, Yifang Ma, Brian Uzzi, *Proceedings of the National Academy of Sciences* **115**(50):12608-12615 (2018)

6. Quantifying patterns of research-interest evolution, Tao Jia, Dashung Wang, Boleslaw K. Szymanski *Nature Human Behaviour* **1**(4):0078, (2017)

7. Quantifying the evolution of individual scientific impact, Roberta Sinatra, Dashun Wang, Pierre Deville, Chaoming Song, Albert-László Barabási, *Science* **354**(6312):5239 (2016)

8. Universal resilience patterns in complex networks, Jianxi Gao, Baruch Barzel, Albert-László Barabási, *Nature* **530**(7590):307 (2016)

9. Human symptoms–disease network, Human, XueZhong Zhou, Jörg Menche, Albert-László Barabási, Amitabh Sharma, *Nature Communications* **5**(4212) (2014)

10. A network framework of cultural history, Maximilian Schich, Chaoming Song, Yong-Yeol Ahn, Alexander Mirsky, Mauro Martino, Albert-László Barabási, *Science* **345** (6196):558-562 (2014)

11. Quantifying Long-Term Scientific Impact, Dashun Wang, Chaoming Song, Albert-László Barabási, *Science* **342** (6154):127-132 (2013)

12. A universal model for mobility and migration patterns, Filippo Simini, Marta C. González, Amos Maritan, Albert-László Barabási, *Nature* **484**:96–100 (2012)

13. Controllability of complex networks, Yang-Yu Liu, Jean-Jacques Slotine, Albert-László Barabási, *Nature* **473**:167–173 (2011)

14. Limits of Human Mobility, Chaoming Song, Zehui Qu, Nicholas Blumm, Albert-László Barabási1, *Science* **327**(5968):1018-1021 (2010)

15. Understanding individual human mobility patterns, Marta C Gonzalez, Cesar A Hidalgo, Albert-Laszlo Barabasi, *Nature*, **453** (7196):779—782 (2008)

16. The product space conditions the development of nations, Cesar A Hidalgo, Bailey Klinger, Albert-László Barabási, Ricardo Hausmann, *Science* **317** (5837):482-487 (2007)

17. Dynamics of ranking, Gerardo Iniguez, Carlos Pineda, Carlos Gershenson, Albert-László Barabási, *Nature Communications* **13** (7):1-7 (2022)

18. Polarization and tipping points, Michael W. Macy, Manqing Ma, Daniel R. Tabin, Jianxi Gao, Boleslaw K. Szymanski. *Proc. the Nat. Acad. of Sci.,* **118**(50):e2102144118, (2021)

19. Polarized information ecosystems can reorganize social networks via information cascades, Christopher K. Tokita, Andrew M. Guess, Corina E. Tarnita, *Proc. the Nat. Acad. of Sci.,* **118**(50):e2102147118, (2021)

20. Political polarization of news media and influencers on Twitter in the 2016 and 2020 US presidential elections, James Flamino, Alessandro Galeazzi, Stuart Feldman, Michael W. Macy, Brendan Cross, Zhenkun Zhou, Matteo Serafino, Alexandre Bovet, Hernan A. Makse, & Boleslaw K. Szymanski, *Nature Human Behaviour* **7**, March 13, 2023. https://doi.org/10.1038s41562-023-01550-8

21. Creation, Evolution, and Dissolution of Social Groups, James Flamino, Boleslaw K. Szymanski, Ashwin Bahulkar, Kevin Chan, and Omar Lizardo, *Scientific Reports* **11**:17470, (2021)

Limits of Predictability in Human Mobility

Motivation: Why do people study human mobility?

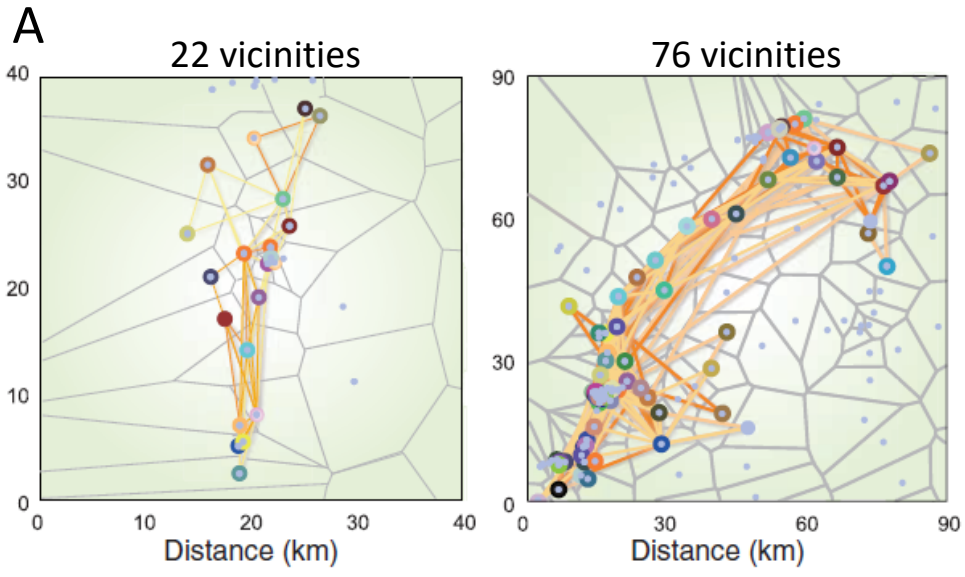
Urban planning and traffic forecasting

Mobile resource management

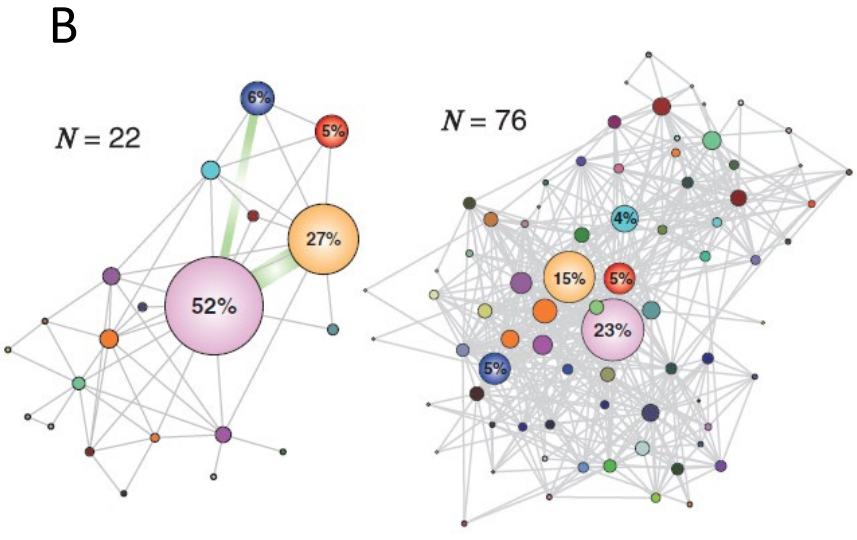
Spread of infectious diseases

Spread of electronic viruses

Limits of Predictability in Human Mobility



The trajectories of two users



User's mobility networks

Quantifying patterns of research-interest evolution

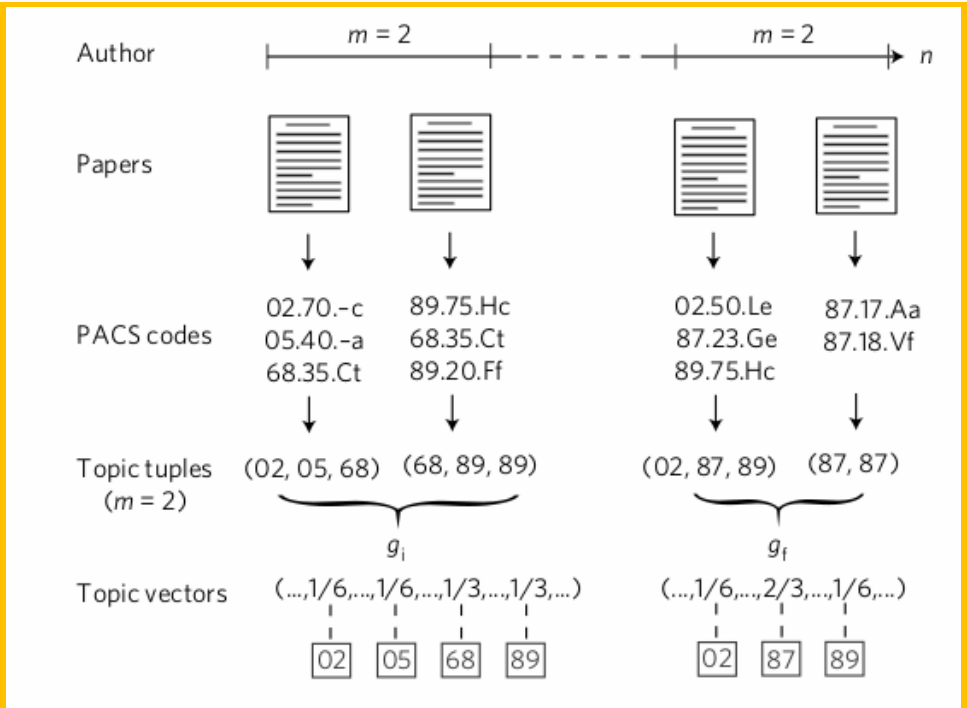
Motivation

- Microscopic factors extensively studied
  - Personality traits
  - Risk aversion
  - Training and mentorship
  - Funding or collaboration opportunities
  - Age
- Research into macroscopic patterns limited
- Researcher’s interest evolution best captured through papers published

Quantifying patterns of research-interest evolution

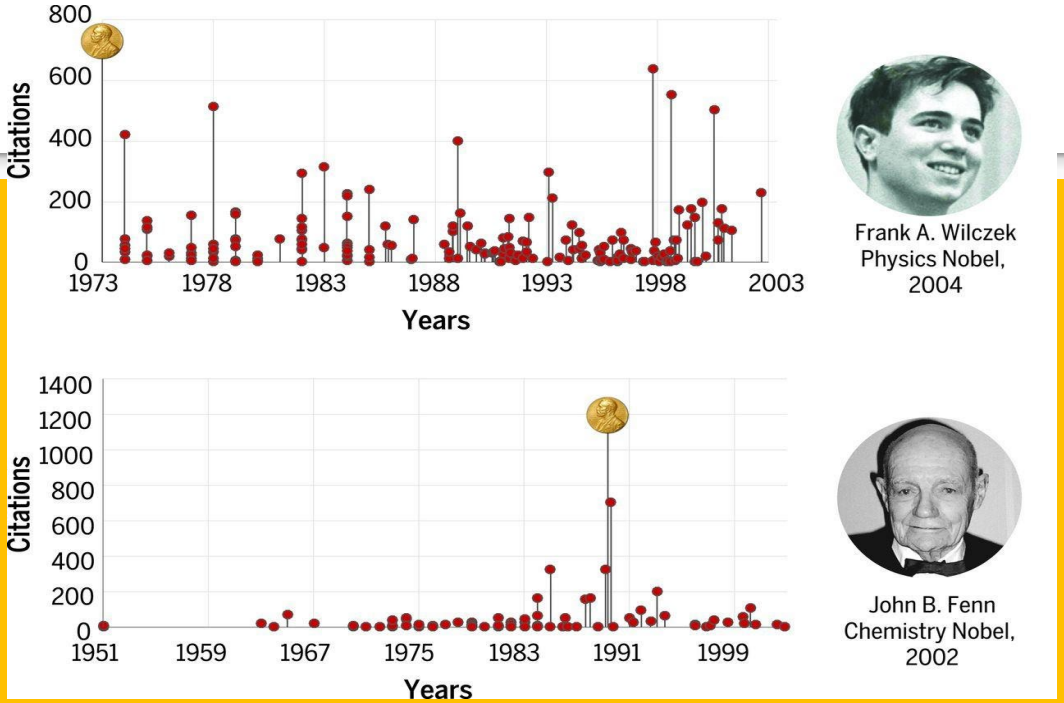
Data

- Uses APS data base
- Transform PACS codes to Topic Vector



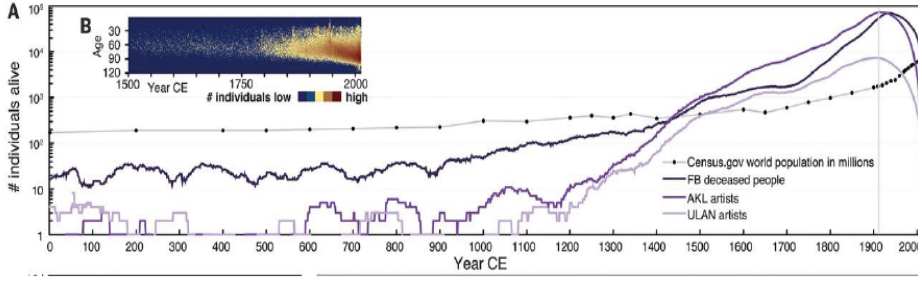
Quantifying the evolution of individual scientific impact

Random-impact model (R-Model)

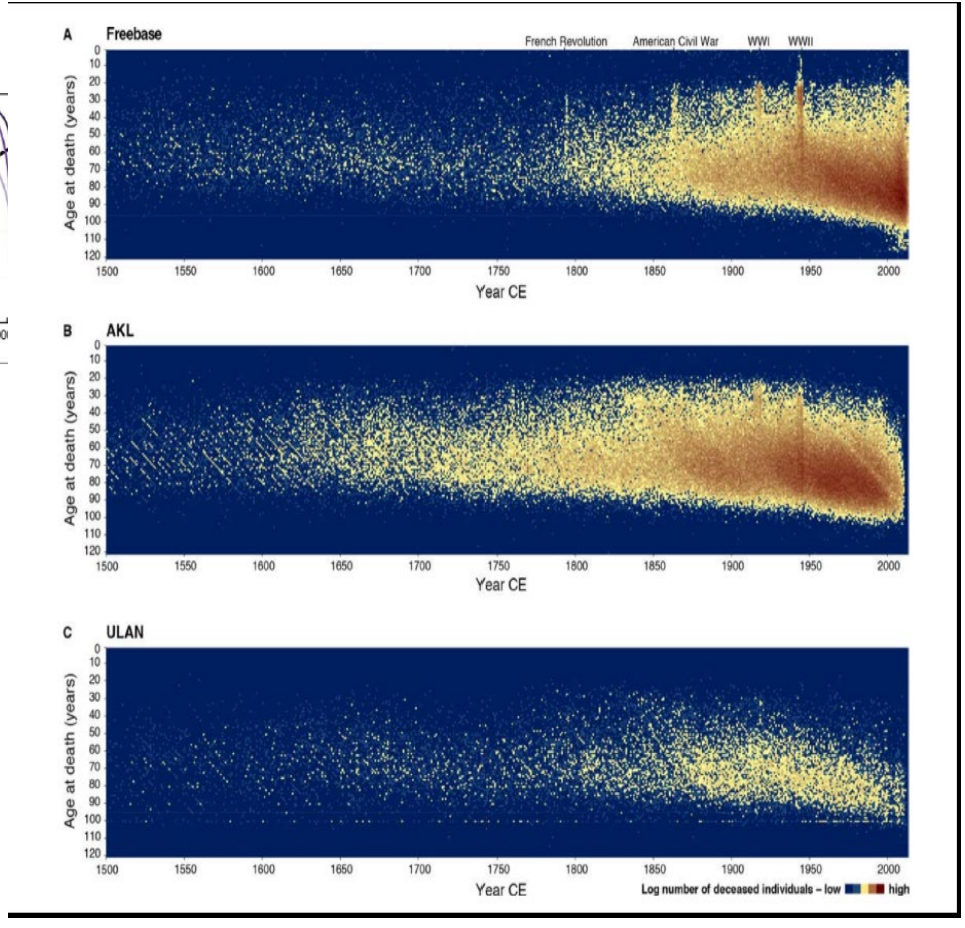


- J ki j guv'ko r cev'y qtm'ecp'qeewt'cv'cp{'r qkpv'kp'c'uekgpvkuvū'ectggt'tgi ctfnguu'qh' hkgnf."eqmcdqtcvqtu."cpf'r tqf wevkxkv{0'P wm'o qf gnhqt'f gvgto kpkpi 'j qy 'c'uekgpvkuvū' kpf kxkf wcn'cdkkv{"chhgev'vj g's wcnkv{"qh'uekgpvkhke'y qtm0

A network framework of cultural history



Data sources, coverage
in time and space

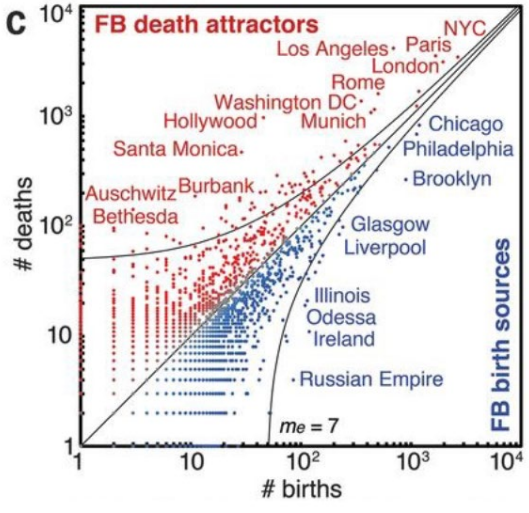


Prominent people are born everywhere but they die in prominent places

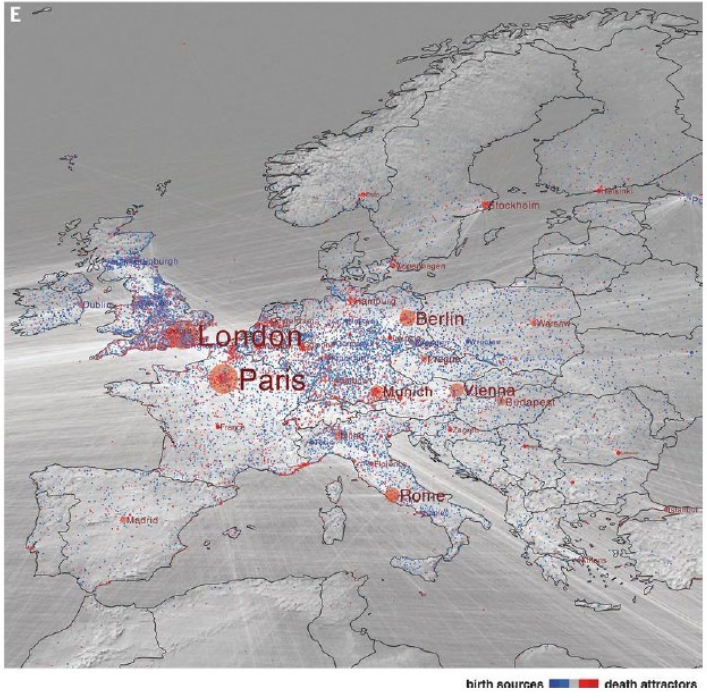
Why?

You cannot choose where you are born but you can choose where you die

Births Vs Deaths

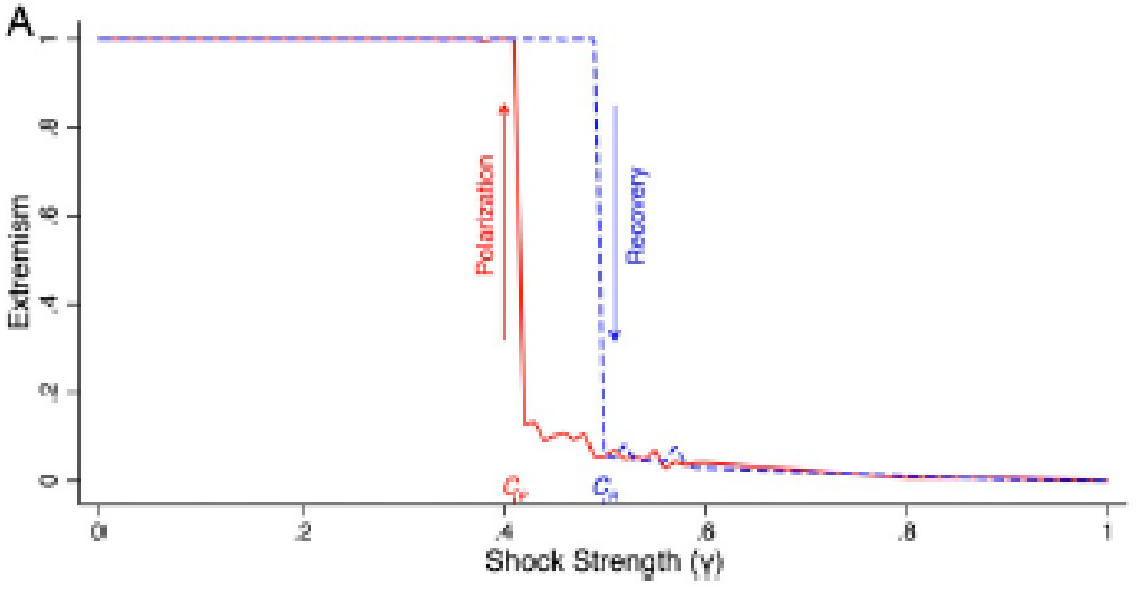


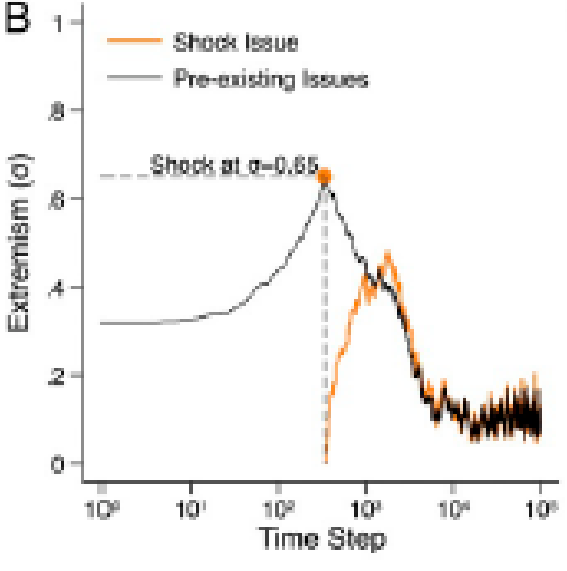
Birth and Death Nodes Geographically Plotted

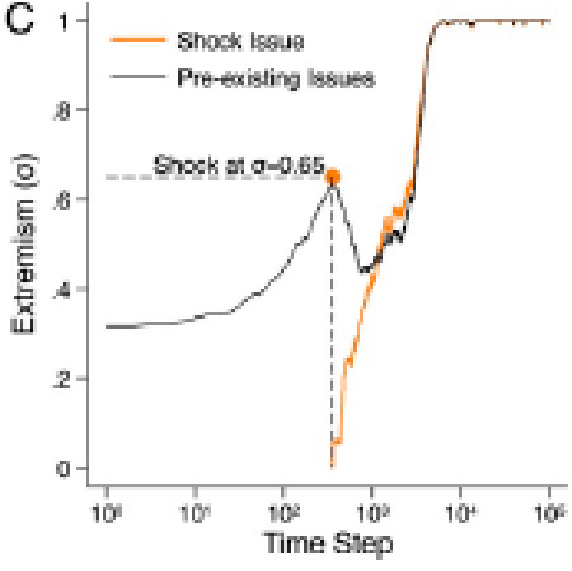


Polarization and tipping points

Importance of the exogenous shock







Free Topic: Ice-Sheet Meshes and Biconnectivity

Motivation

https://insideclimatenews.org/sites/default/files/styles/icn_full_wrap_wide/public/getz-ice-shelf_jeremy-harbeck-nasa.jpg?itok=D1uLzpFu

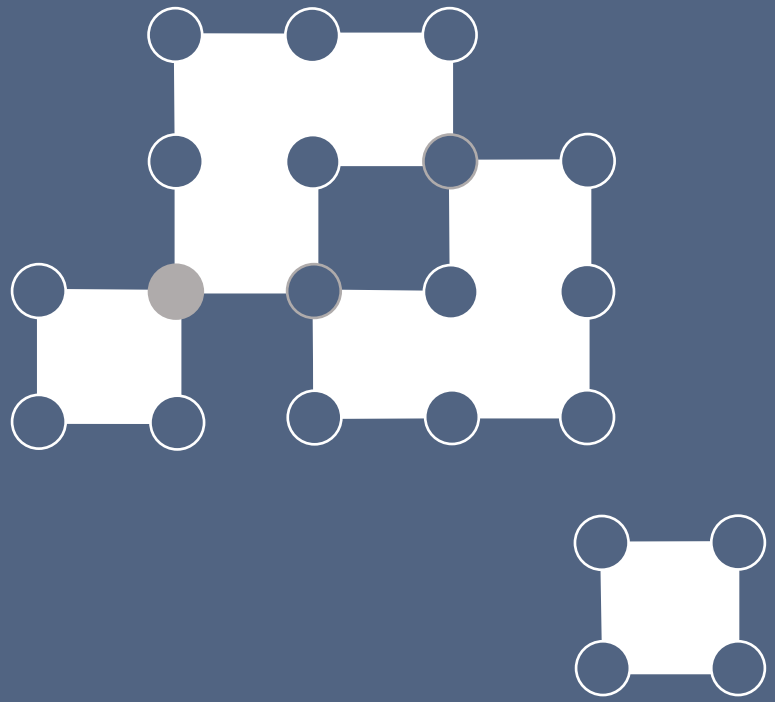
Ice-Sheet Meshes and Biconnectivity

Background

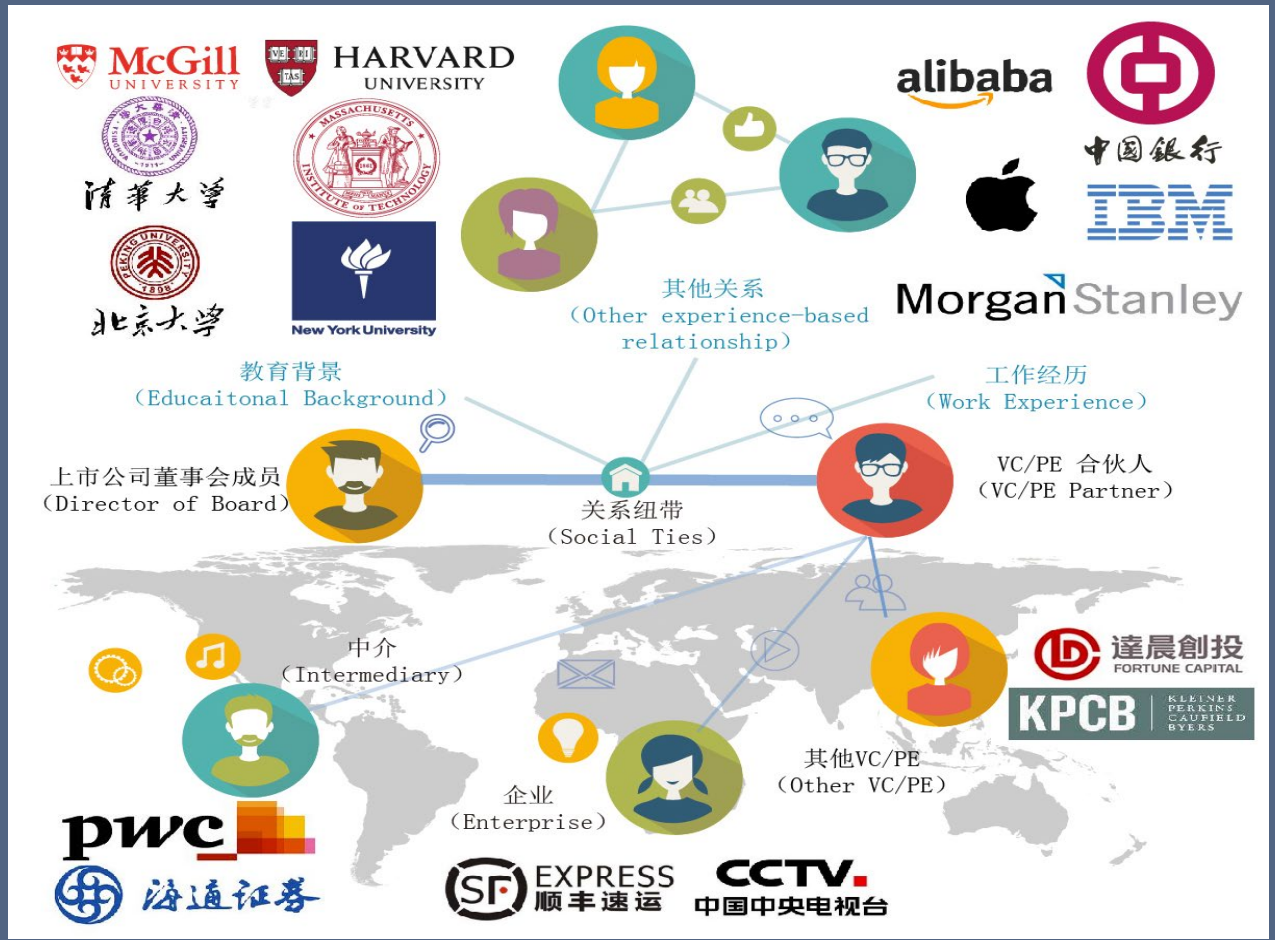
- Biconnectivity
  - Articulation points
- Meshes
  - Potential articulation points
  - “Double hinges”

The Ice-Sheet problem

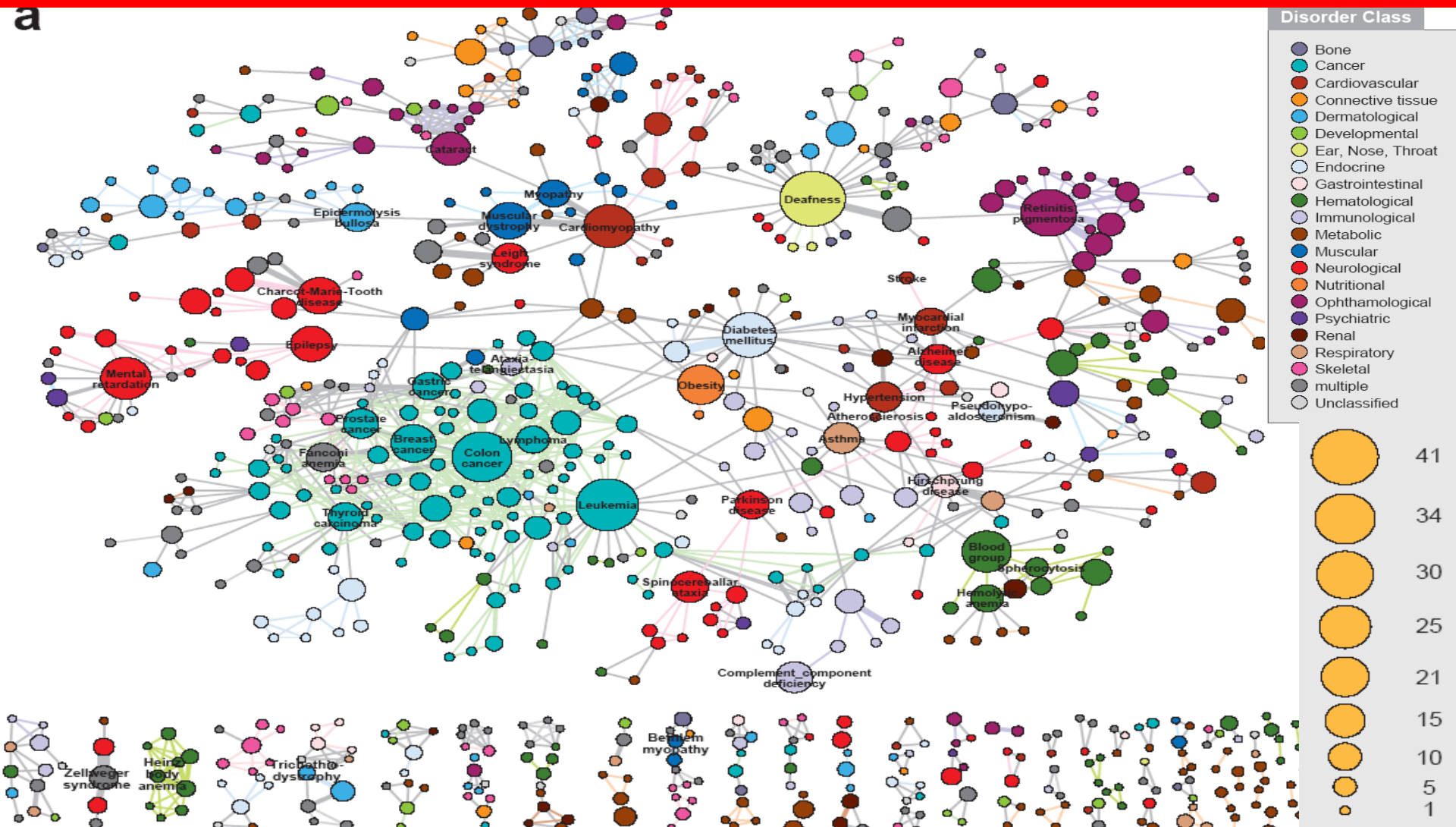
- Modeling Antarctic Ice-Sheet
- “Grounding”
- Degenerate Features
- Similar to Biconnectivity



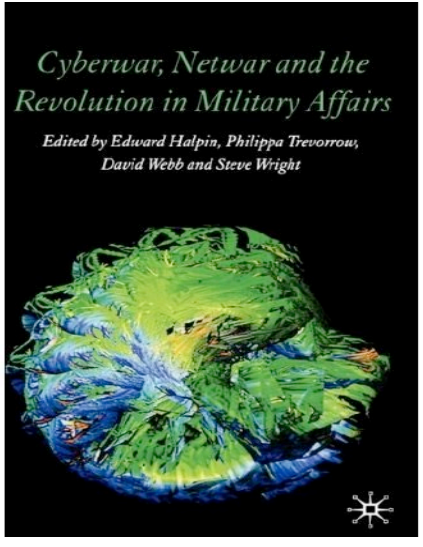
Free Topic: Links between Startups and Venture Capital in China

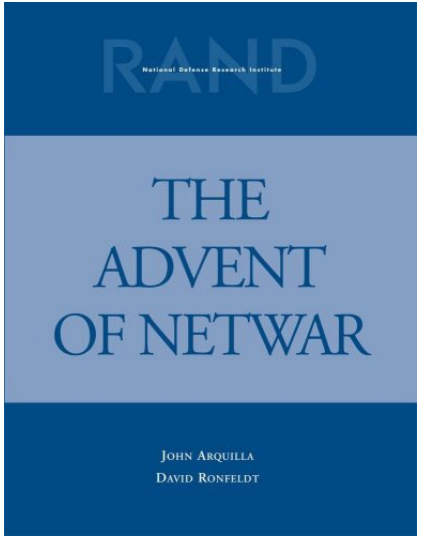


HUMAN DISEASE NETWORK



FIGHTING TERRORISM AND MILITARY

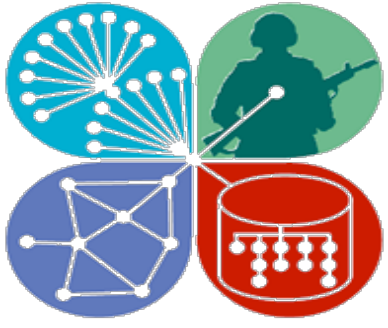




http://www.slate.com/id/2245232

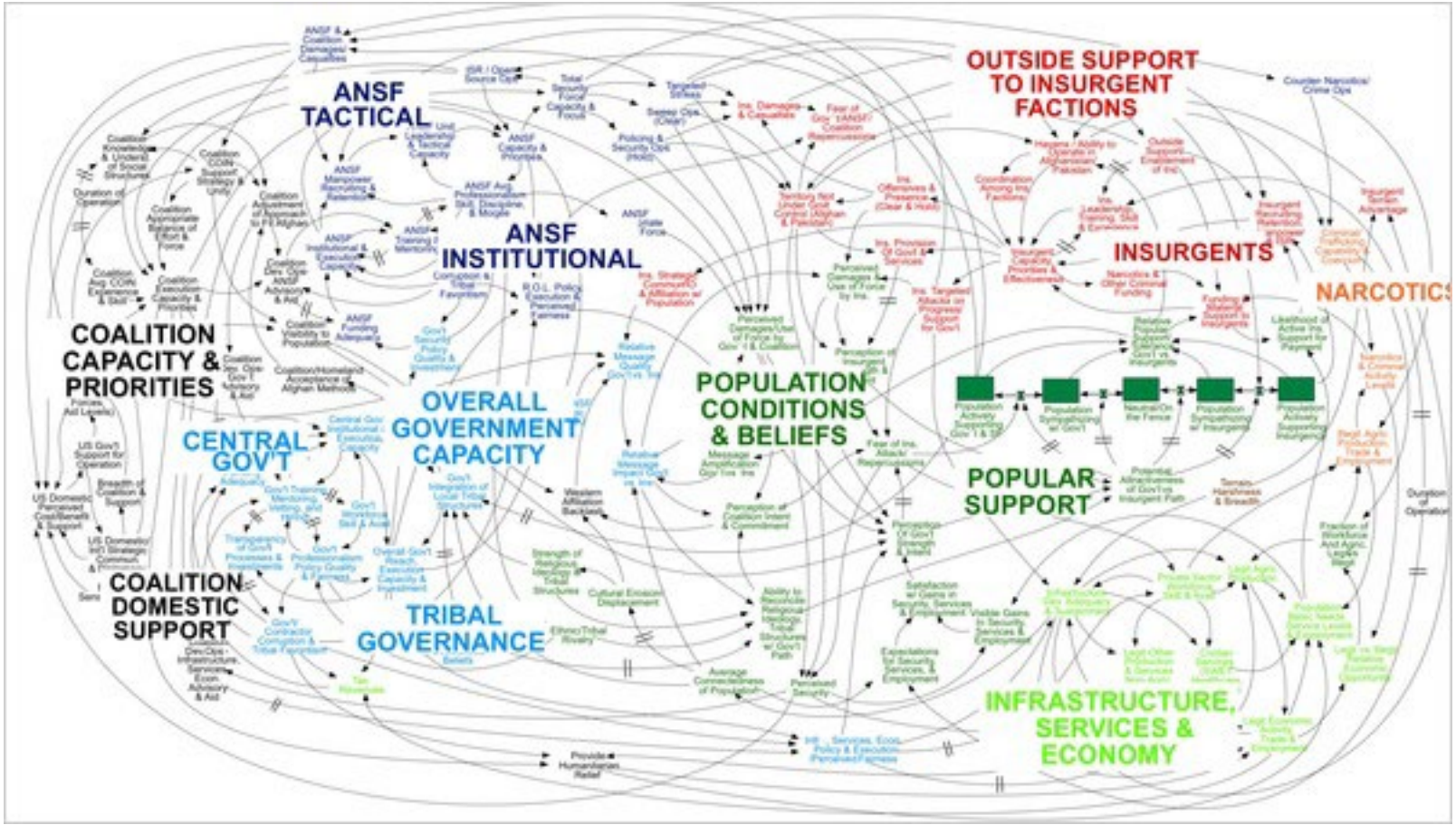
FIGHTING TERRORISM AND MILITARY

Network Science Center
West Point



http://www.ns-cta.org/ns-cta-blog/

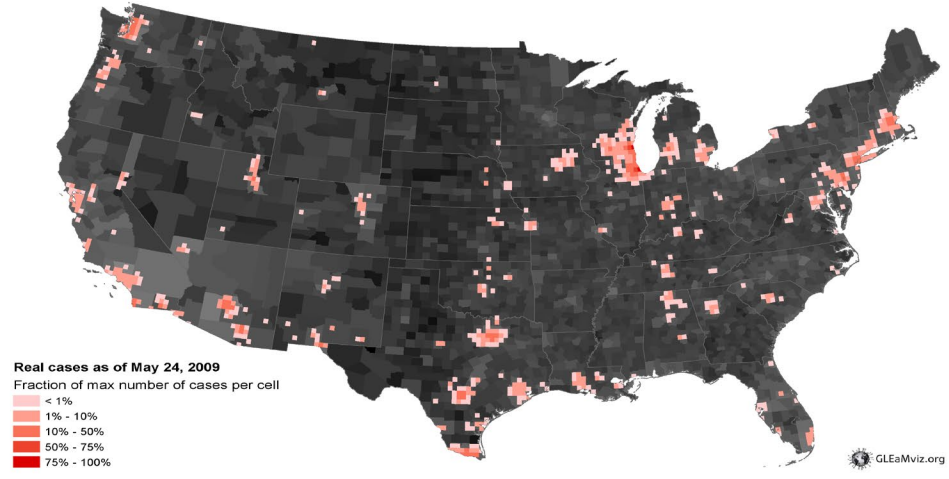
The network behind a military engagement



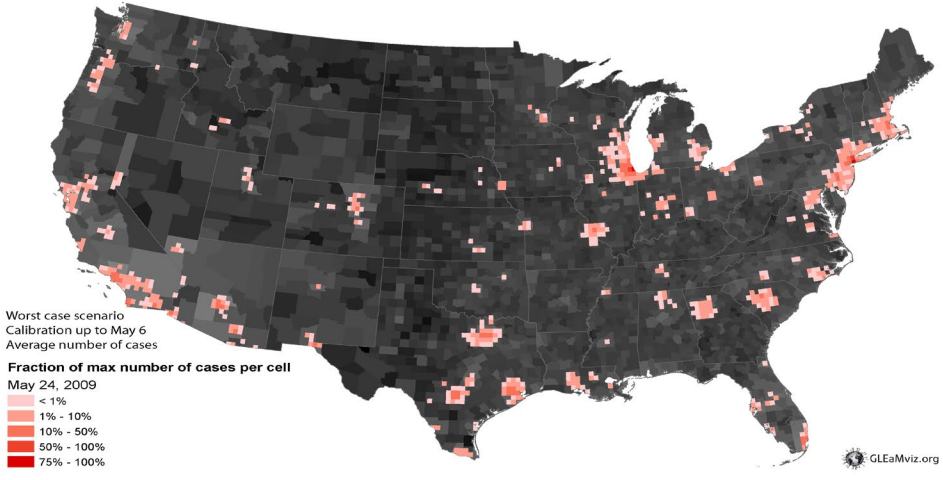
EPIDEMIC FORECAST

Predicting the H1N1 pandemic

Real

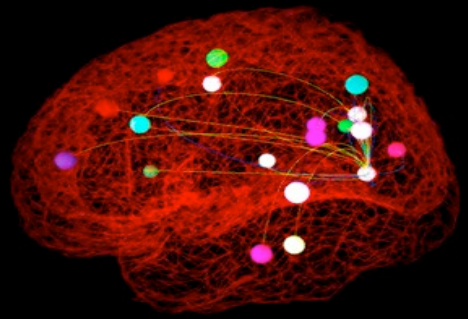


Projected

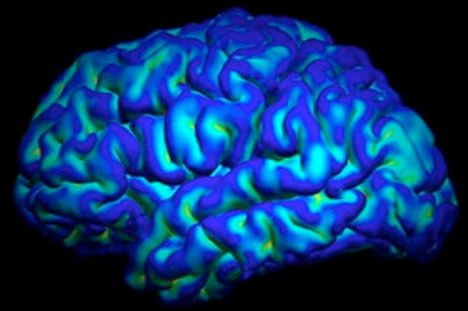


BRAIN RESEARCH

In September 2010 the National Institutes of Health awarded $40 million to researchers at Harvard, Washington University in St. Louis, the University of Minnesota and UCLA, to develop the technologies that could systematically map out brain circuits.

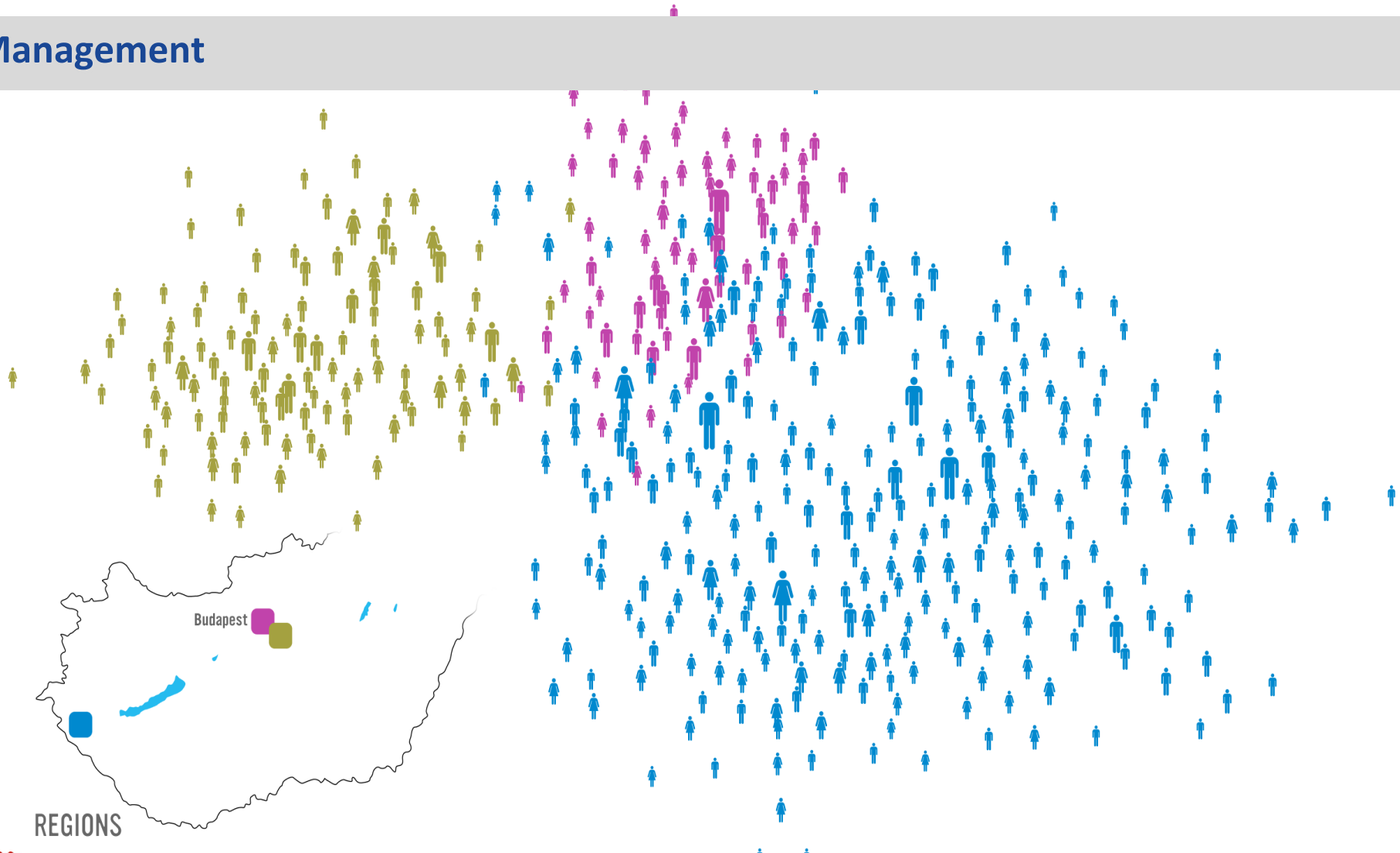


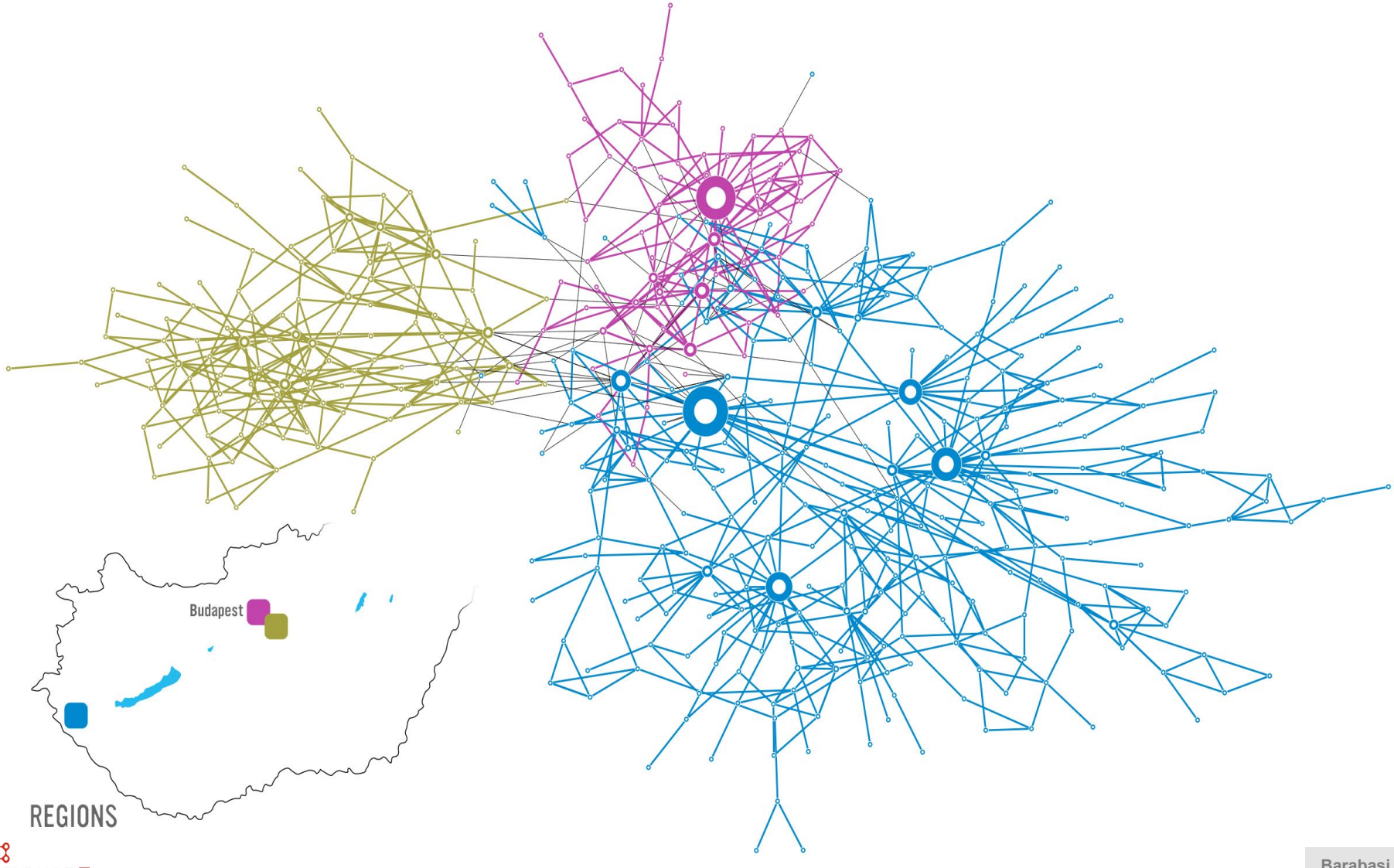
The Human Connectome Project (HCP) with the ambitious goal to construct a map of the complete structural and functional neural connections in vivo within and across individuals.



http://www.humanconnectomeproject.org/overview/

Management

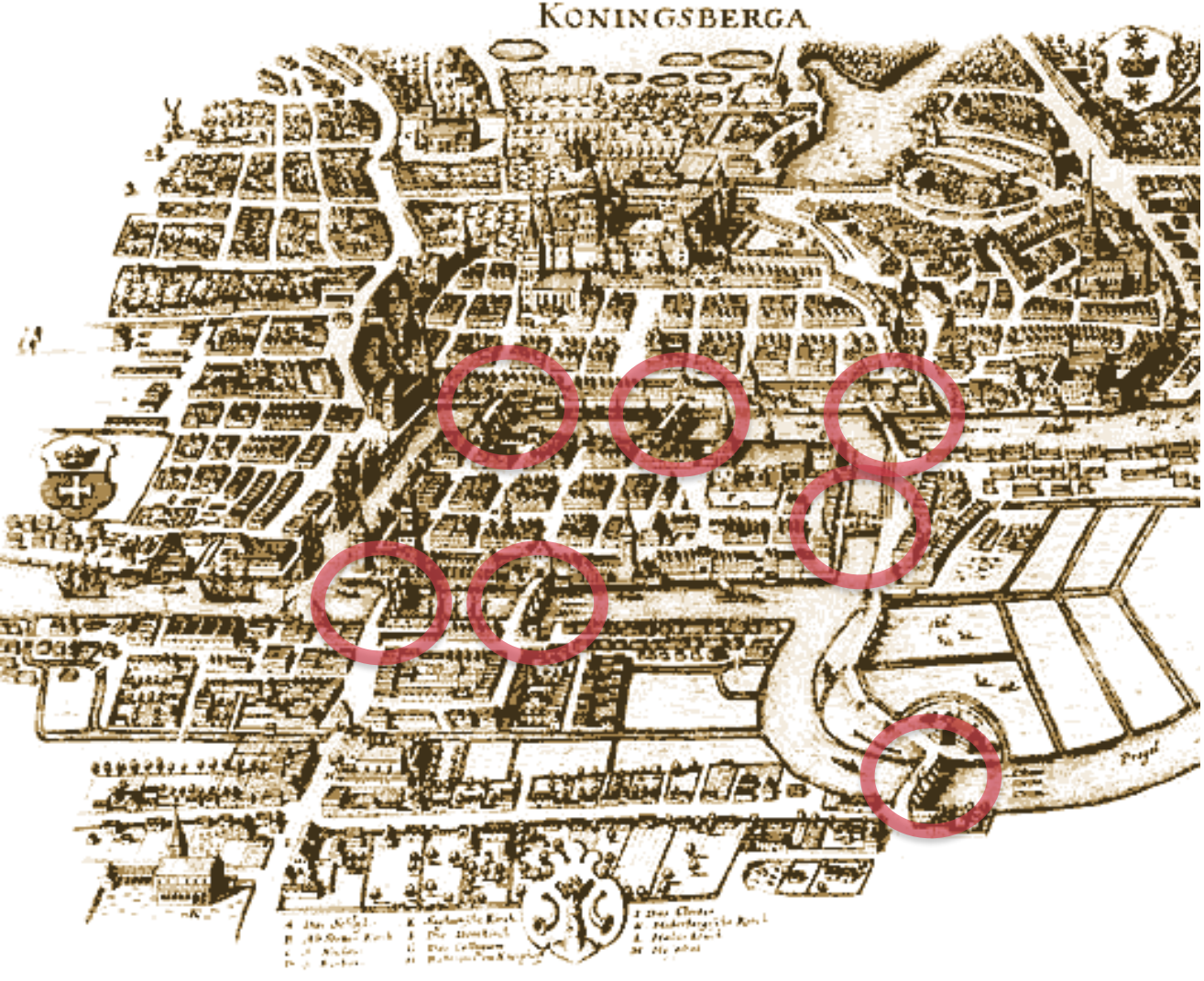





1
2
22 LINKS

The Bridges of Konigsberg

THE BRIDGES OF KONIGSBERG



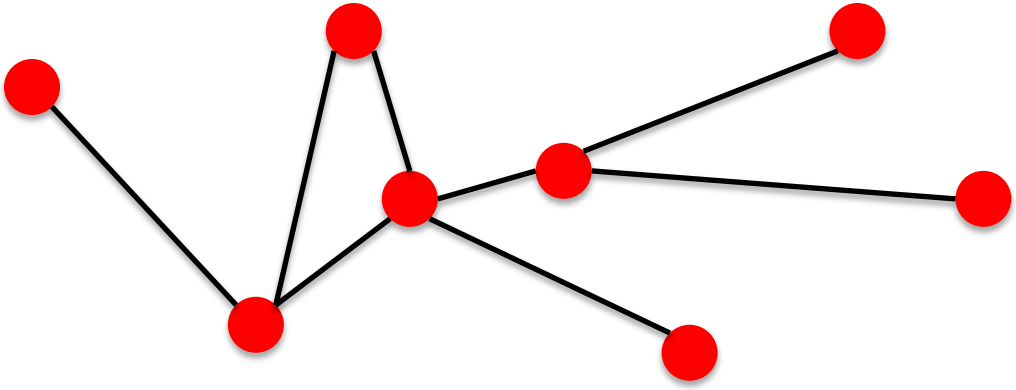
Can one walk across the seven bridges and never cross the same bridge twice?

THE BRIDGES OF KONIGSBERG

http://www.numericana.com/answer/graphs.htm

Networks and graphs

COMPONENTS OF A COMPLEX SYSTEM



- **components**: nodes, vertices N
- **interactions**: links, edges L
- **system**: network, graph (N,L)

NETWORKS OR GRAPHS?

network often refers to real systems

- www,
- social network
- metabolic network.

Language: (Network, node, link)

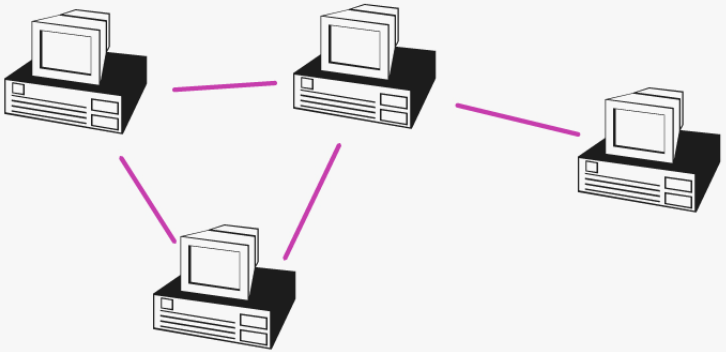
graph: mathematical representation of a network

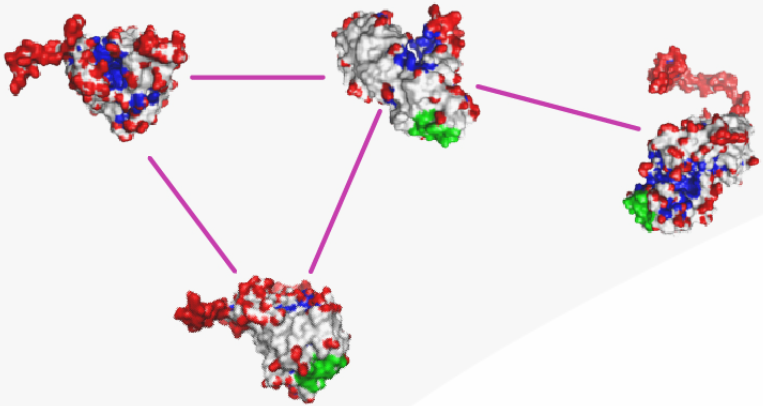
- web graph,
- social graph (a Facebook term)

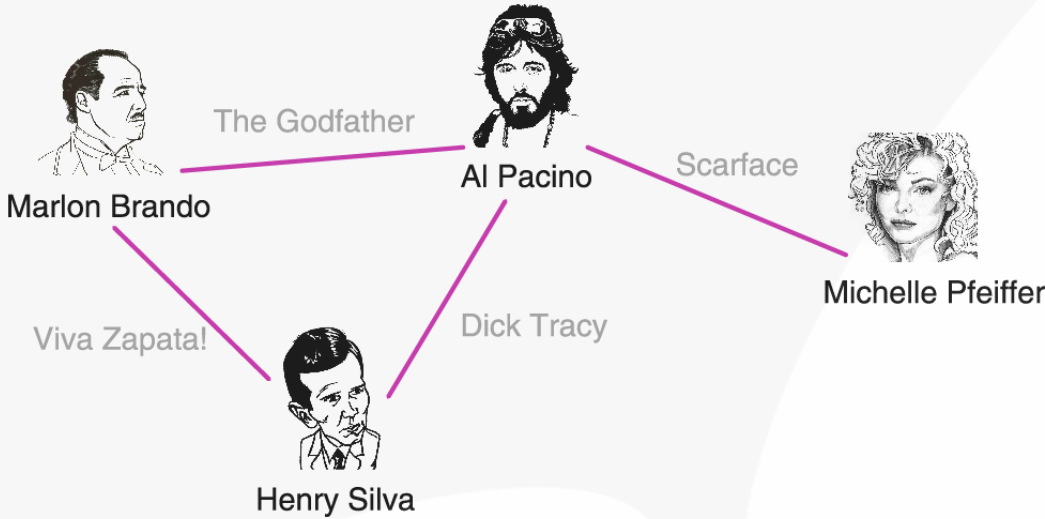
Language: (Graph, vertex, edge)

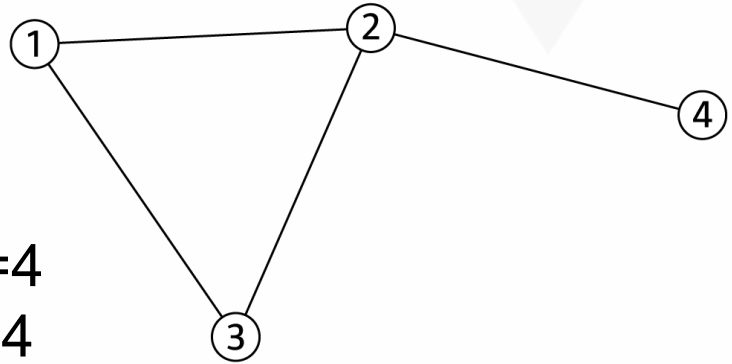
We will try to make this distinction whenever it is appropriate, but in most cases we will use the two terms interchangeably.

A COMMON LANGUAGE









N=4
L=4

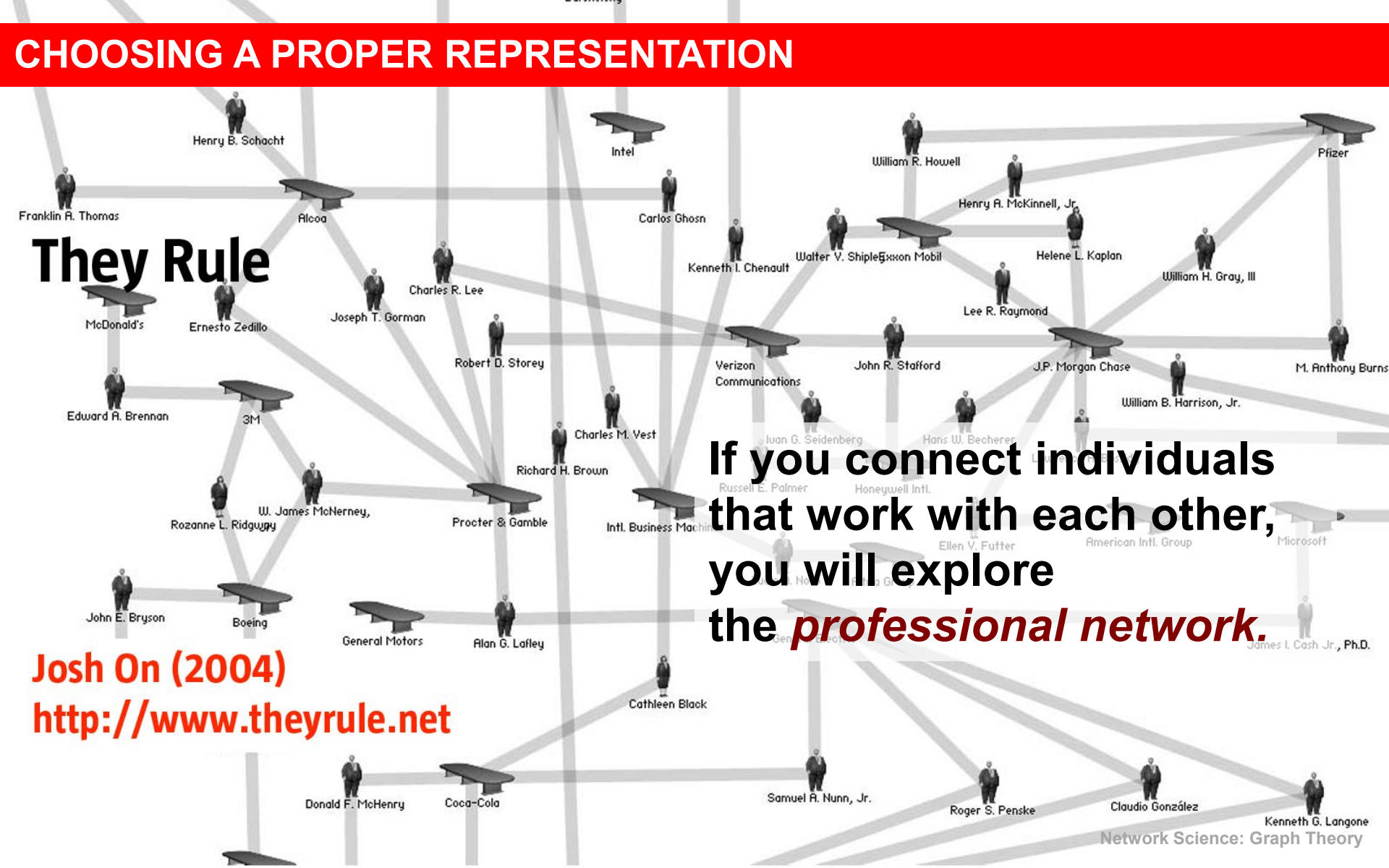
CHOOSING A PROPER REPRESENTATION

The choice of the proper network representation determines our ability to use network theory successfully.

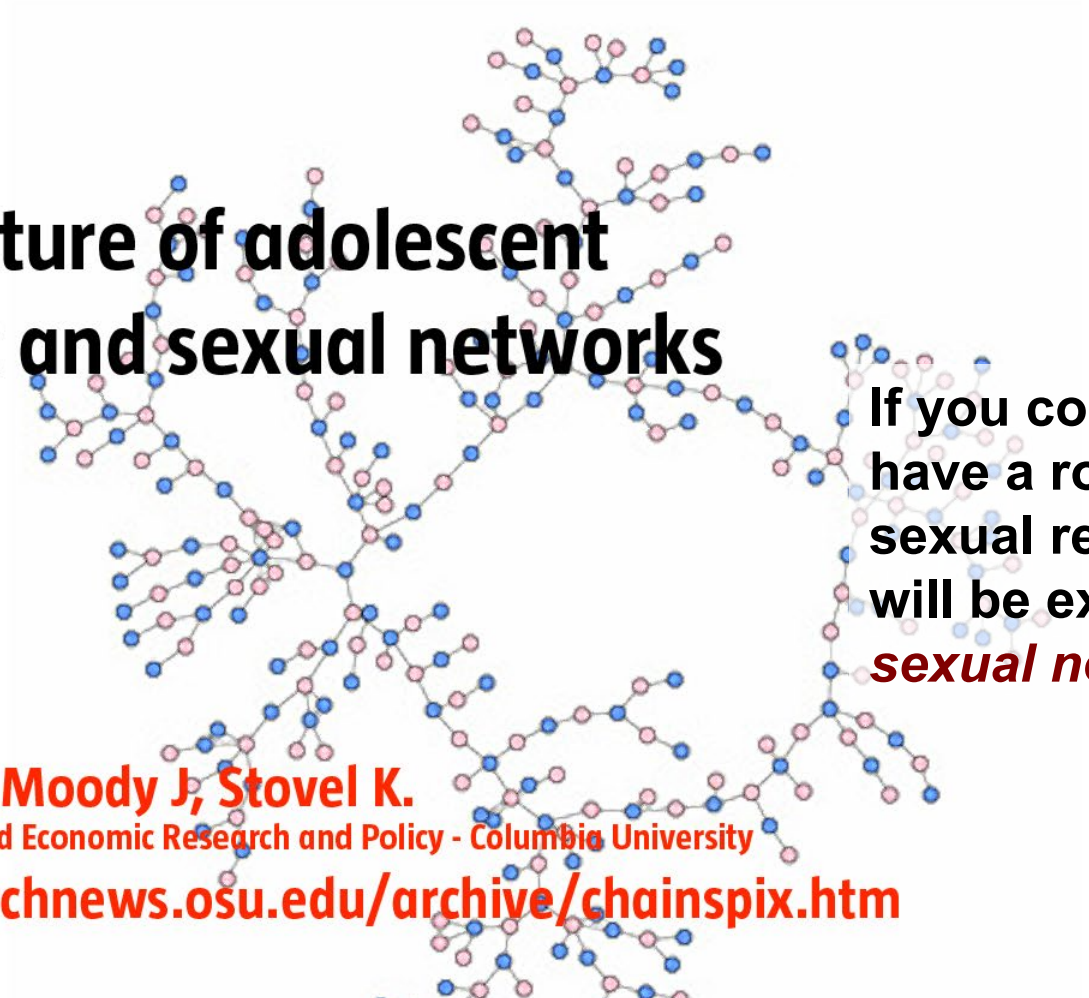
In some cases there is a unique, unambiguous representation.
In other cases, the representation is by no means unique.

For example, the way we assign the links between a group of individuals will determine the nature of the question we can study.

CHOOSING A PROPER REPRESENTATION



CHOOSING A PROPER REPRESENTATION



The structure of adolescent romantic and sexual networks

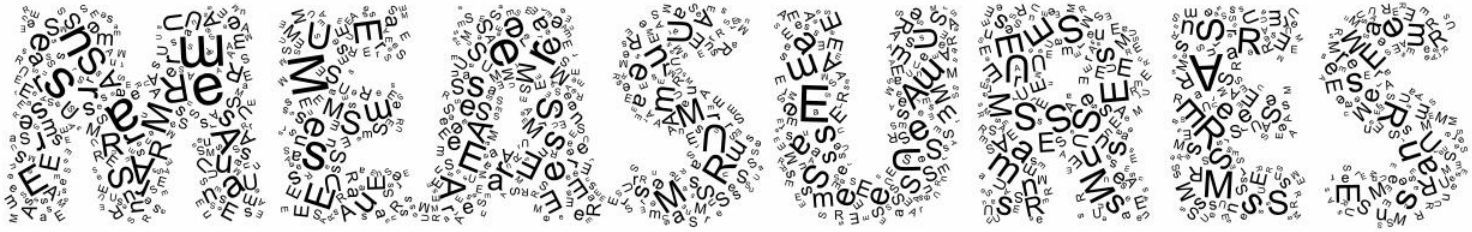
If you connect those that have a romantic and sexual relationship, you will be exploring the *sexual networks*.

Bearman PS, Moody J, Stovel K.
Institute for Social and Economic Research and Policy - Columbia University
http://researchnews.osu.edu/archive/chainspix.htm

CHOOSING A PROPER REPRESENTATION

If you connect individuals based on their first name (*all Peters connected to each other*), you will be exploring what?

It is a network, nevertheless.

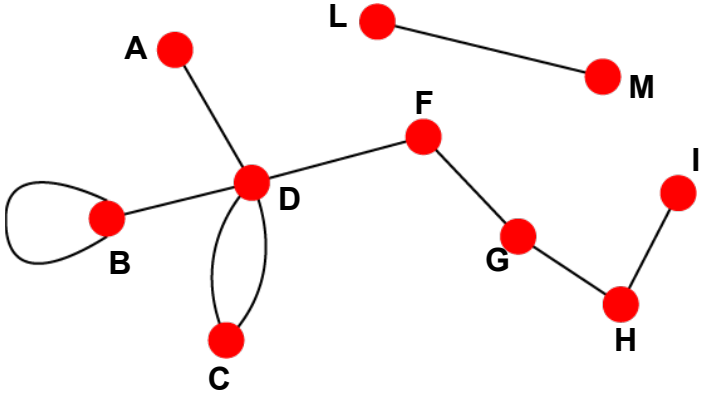

MEASURES

UNDIRECTED VS. DIRECTED NETWORKS

Undirected

Links: undirected (*symmetrical*)

Graph:

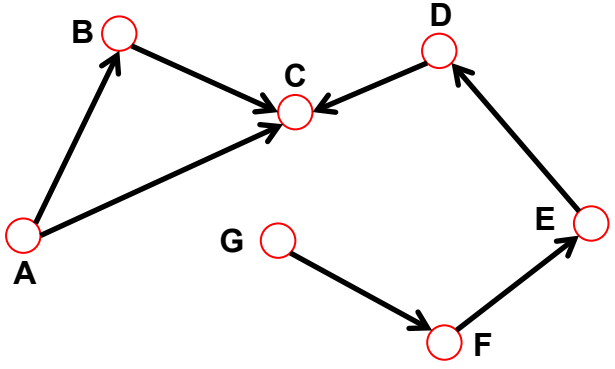


Undirected links :
coauthorship links
Actor network
protein interactions

Directed

Links: directed (*arcs*).

Digraph = directed graph:



An undirected link is the superposition of two opposite directed links.

Directed links :
URLs on the www
phone calls
metabolic reactions

Section 2.2

Reference Networks

NETWORK	NODES	LINKS	DIRECTED UNDIRECTED	N	L
Internet	Routers	Internet connections	Undirected	192,244	609,066
WWW	Webpages	Links	Directed	325,729	1,497,134
Power Grid	Power plants, transformers	Cables	Undirected	4,941	6,594
Mobile Phone Calls	Subscribers	Calls	Directed	36,595	91,826
Email	Email addresses	Emails	Directed	57,194	103,731
Science Collaboration	Scientists	Co-authorship	Undirected	23,133	93,439
Actor Network	Actors	Co-acting	Undirected	702,388	29,397,908
Citation Network	Paper	Citations	Directed	449,673	4,689,479
E. Coli Metabolism	Metabolites	Chemical reactions	Directed	1,039	5,802
Protein Interactions	Proteins	Binding interactions	Undirected	2,018	2,930