A complex network graph background consisting of numerous small white dots (nodes) connected by thin white lines (edges), creating a mesh-like pattern across the entire slide.

DS8104: Network Science

Class 1: Introduction

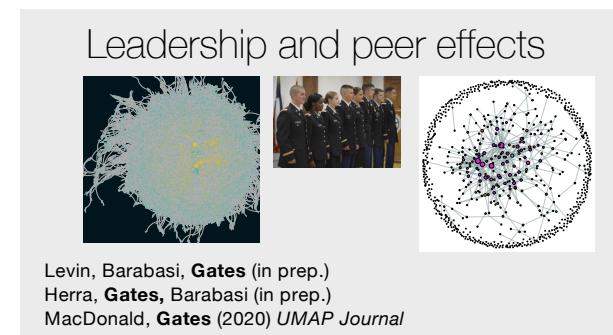
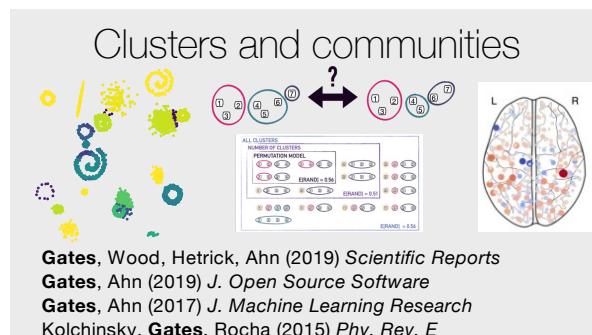
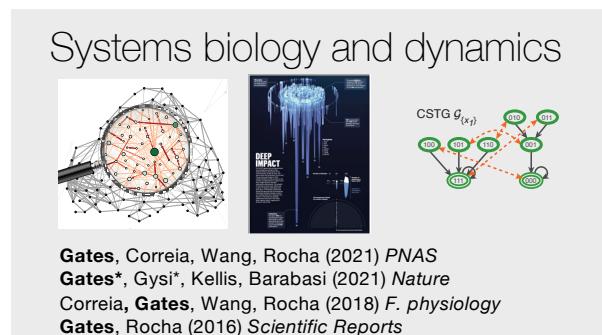
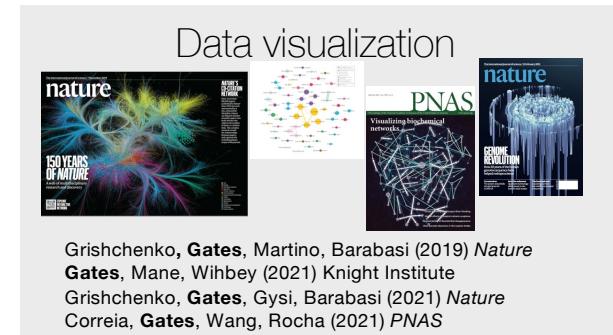
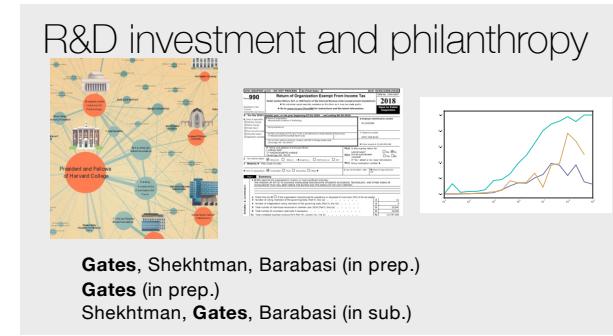
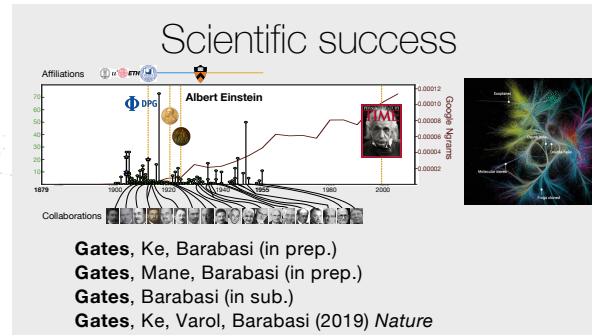
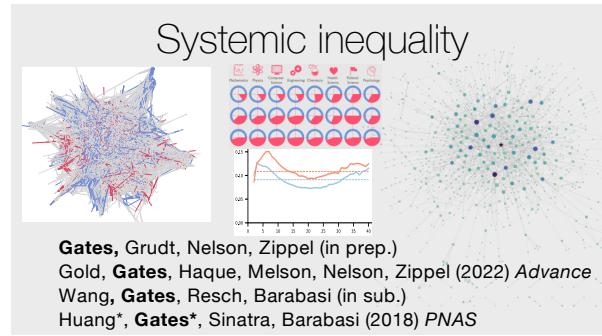
a.k.a. Why are we here?

Alexander Gates

A solid blue horizontal bar located at the bottom of the slide, spanning most of its width.

www.alexandergates.net

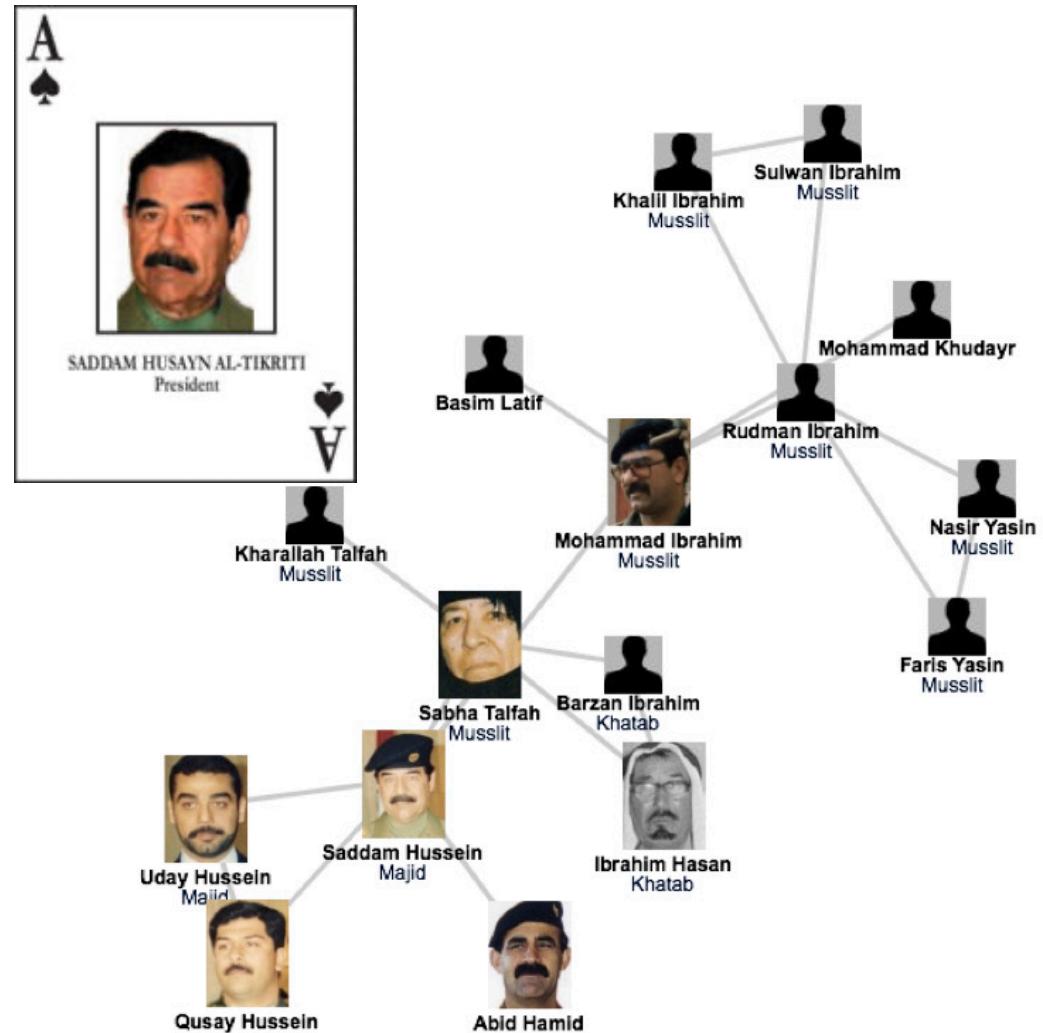
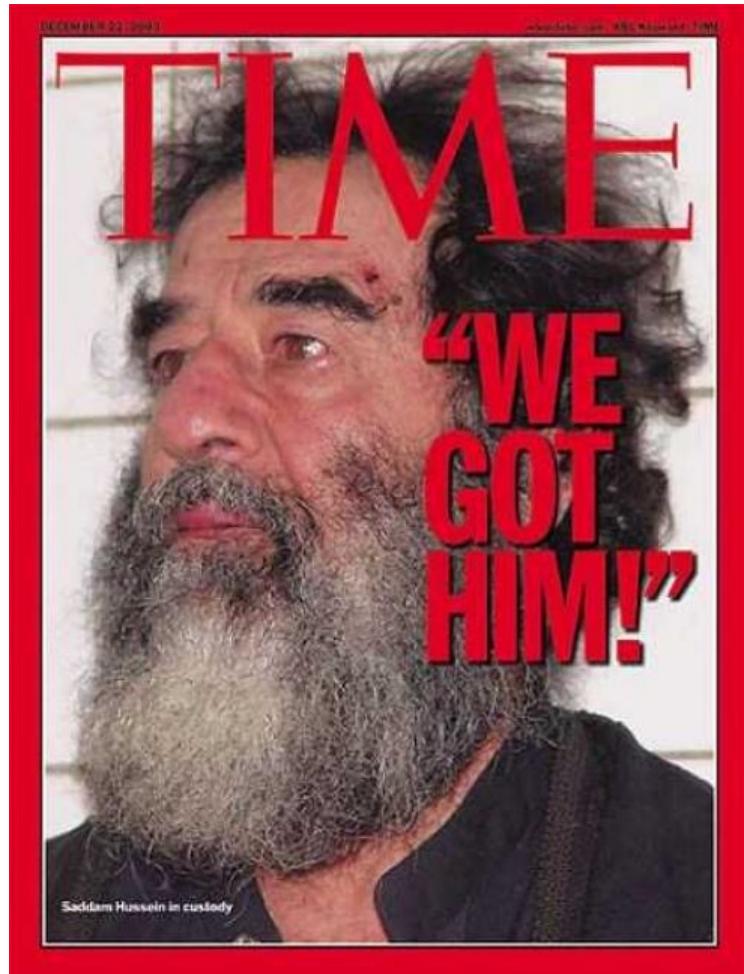
Why am I here?



Why are you here?

Why are we here?

FROM SADDAM HUSSEIN TO NETWORK THEORY



The capture of Saddam Hussein:

shows the strong **predictive power of networks**.

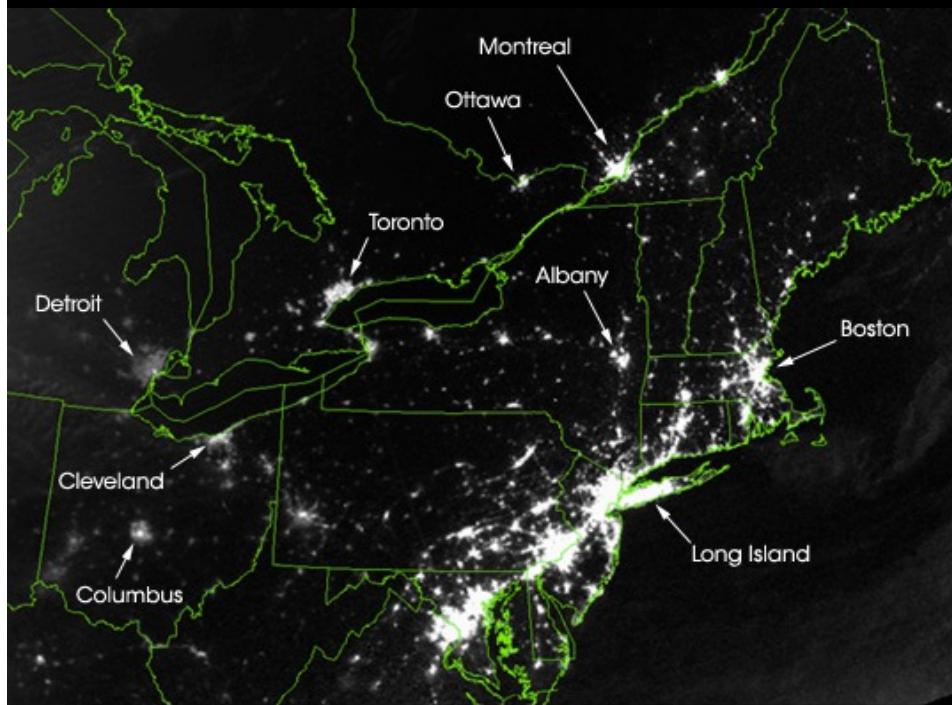
underlies the need to **obtain accurate maps** of the networks we aim to study; and the often heroic difficulties we encounter during the mapping process.

demonstrates the **remarkable stability of these networks**:

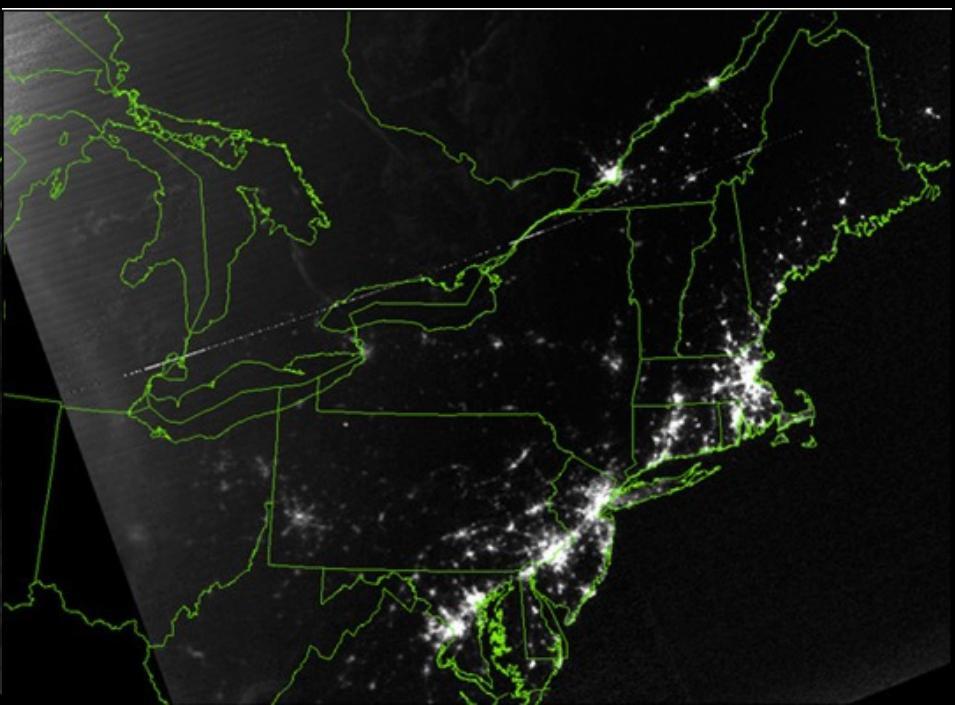
The capture of Hussein was not based on fresh intelligence, but rather on his pre-invasion social links, unearthed from old photos stacked in his family album.

shows that the **choice of network we focus on makes a huge difference**: the hierarchical tree, that captured the official organization of the Iraqi government, was of no use when it came to Saddam Hussein's whereabouts.

VULNERABILITY DUE TO INTERCONNECTIVITY



August 14, 2003: 9:29pm EDT
20 hours before



August 15, 2003: 9:14pm EDT
7 hours after

An important theme of this class:

How does network structure affect the robustness of a complex system?

Develop quantitative tools to assess the interplay between network structure and the dynamical processes on the networks, and their impact on failures.

We will learn that failures reality failures follow reproducible laws, that can be quantified and even predicted using the tools of network science.

NETWORKS AT THE HEART OF
COMPLEX SYSTEMS



*"I think the next century
will be the century
of complexity."*

Stephen Hawking
January 23, 2000

Complex

[adj., v. kuh m-pleks, kom-pleks; n. kom-pleks]

–adjective

1.

composed of many interconnected parts; compound; composite: a complex highway system.

2.

characterized by a very complicated or involved arrangement of parts, units, etc.: complex machinery.

3.

so complicated or intricate as to be hard to understand or deal with: a complex problem.

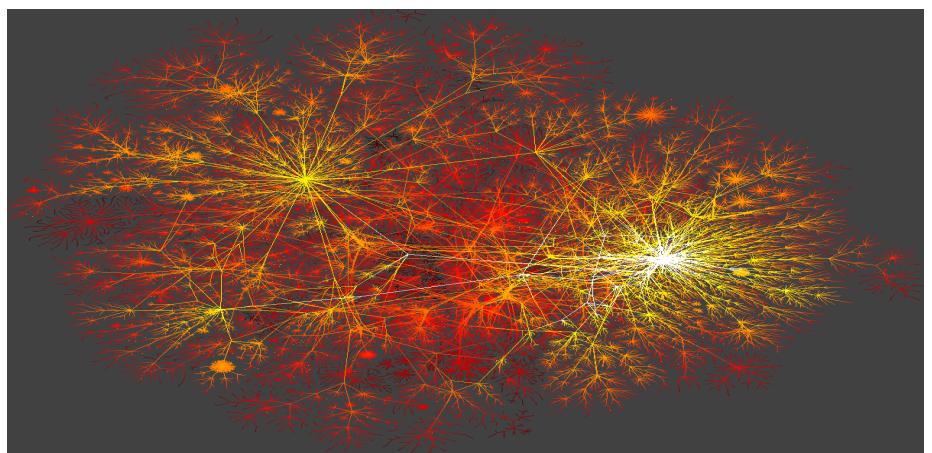
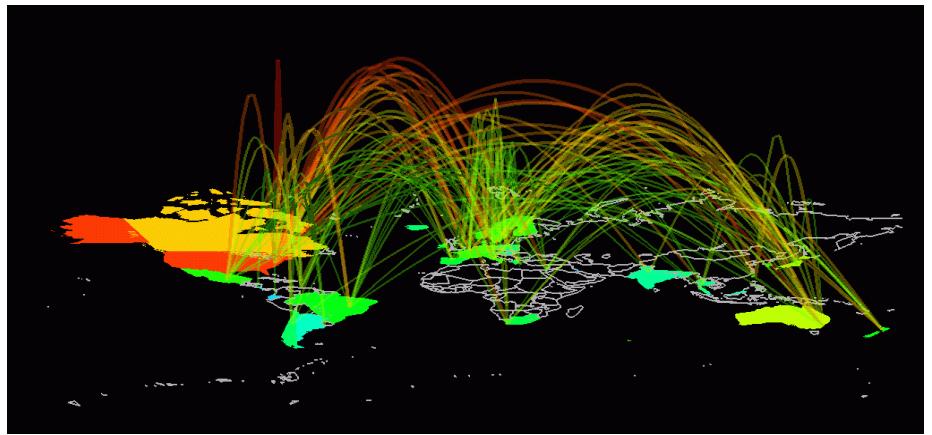
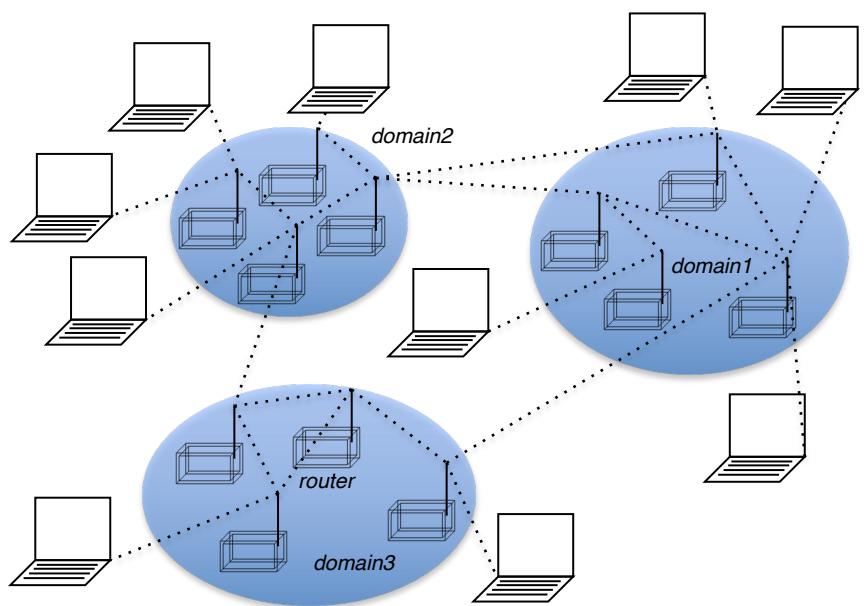
Source: Dictionary.com

Complexity, a scientific theory which asserts that some systems display behavioral phenomena that are completely inexplicable by any conventional analysis of the systems' constituent parts. These phenomena, commonly referred to as emergent behaviour, seem to occur in many complex systems involving living organisms, such as a stock market or the human brain.

Source: John L. Casti, Encyclopædia Britannica

Complexity

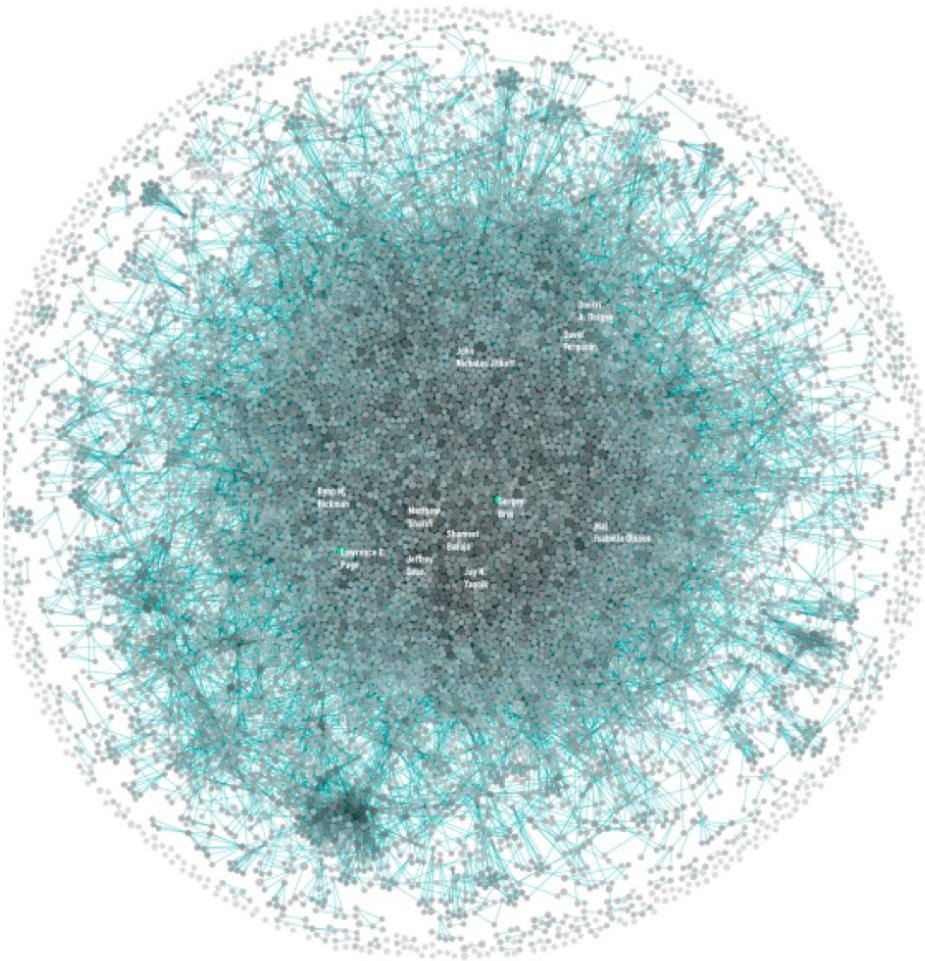
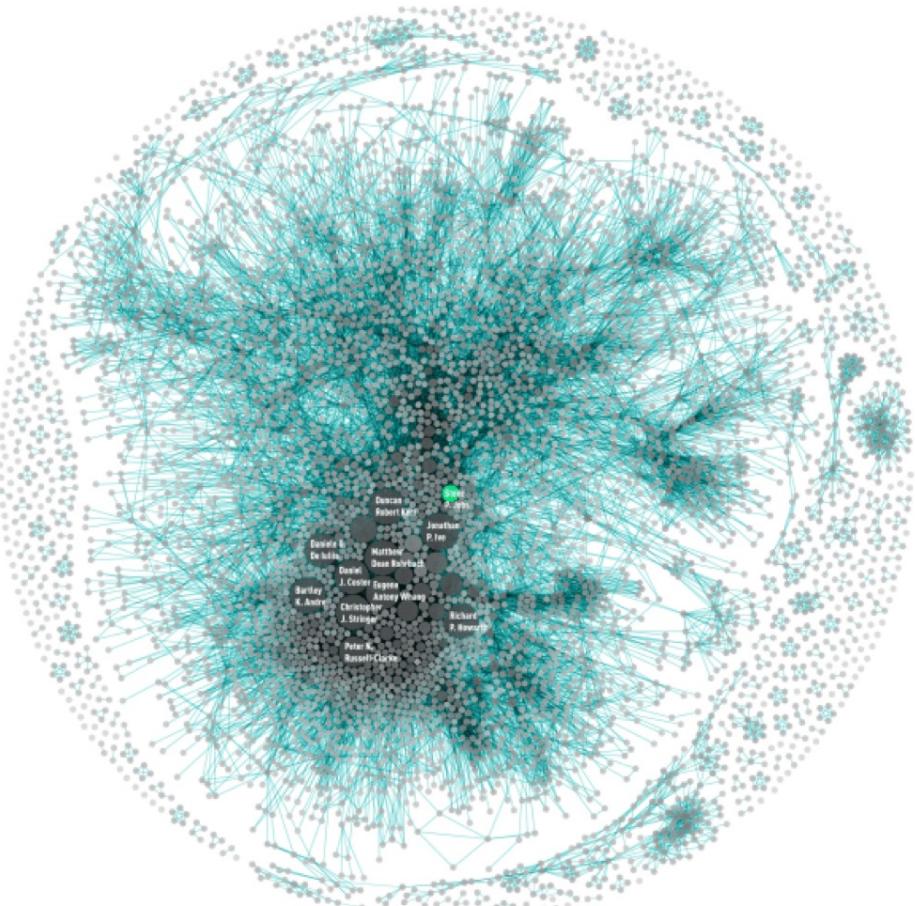
Behind each complex system
there is a **network**, that defines
the interactions between the
component.



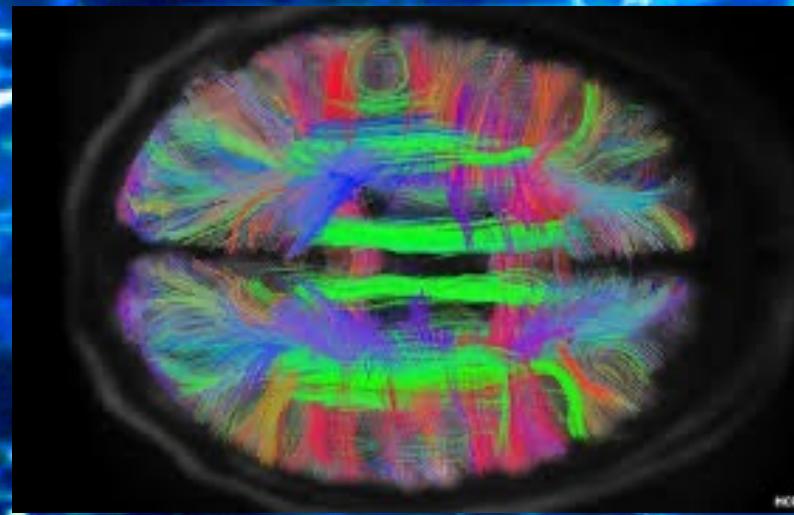


The “Social Graph” behind Facebook (2014)

Keith Shepherd's "Sunday Best". <http://baseballart.com/2010/07/shades-of-greatness-a-story-that-needed-to-be-told/>



Human Brain has between
10-100 billion neurons.

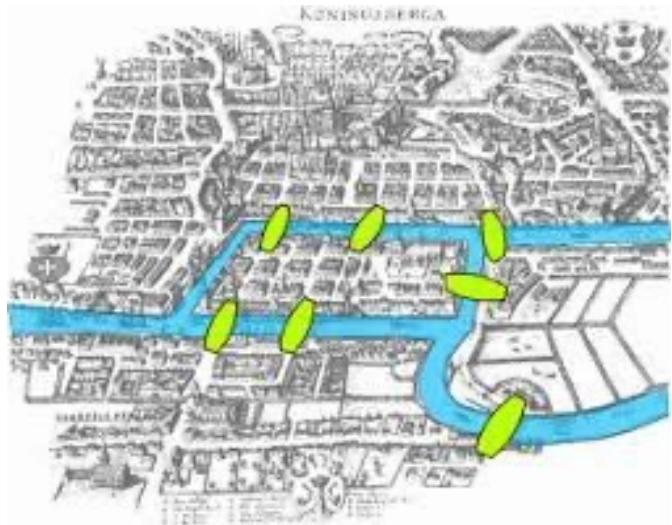


Behind each system studied in complexity there is an intricate wiring diagram, or a network, that defines the interactions between the component.

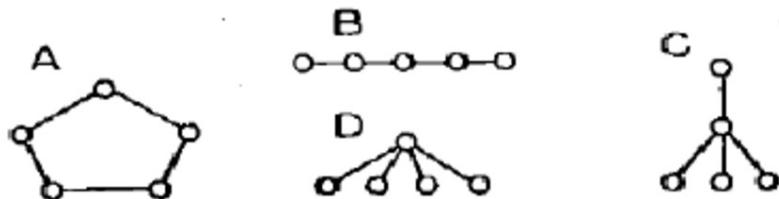
We will never understand complex system unless we map out and understand the networks behind them.

A brief history of networks





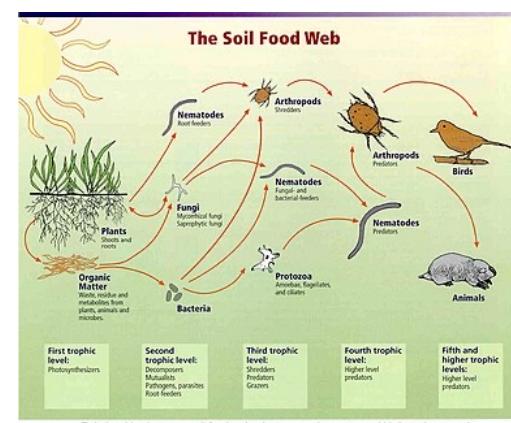
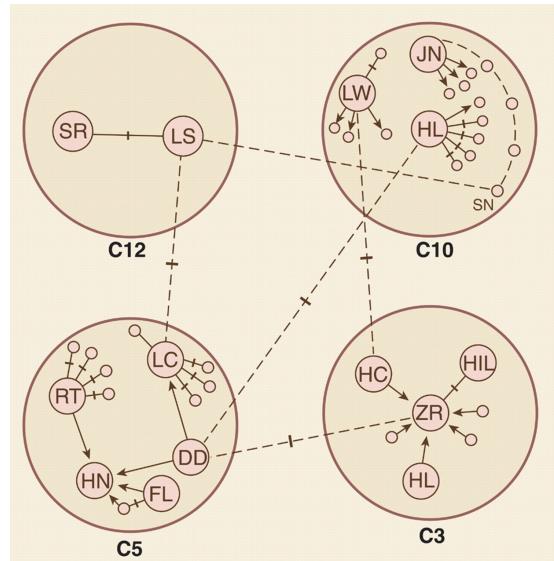
Graph theory:
1735, Euler



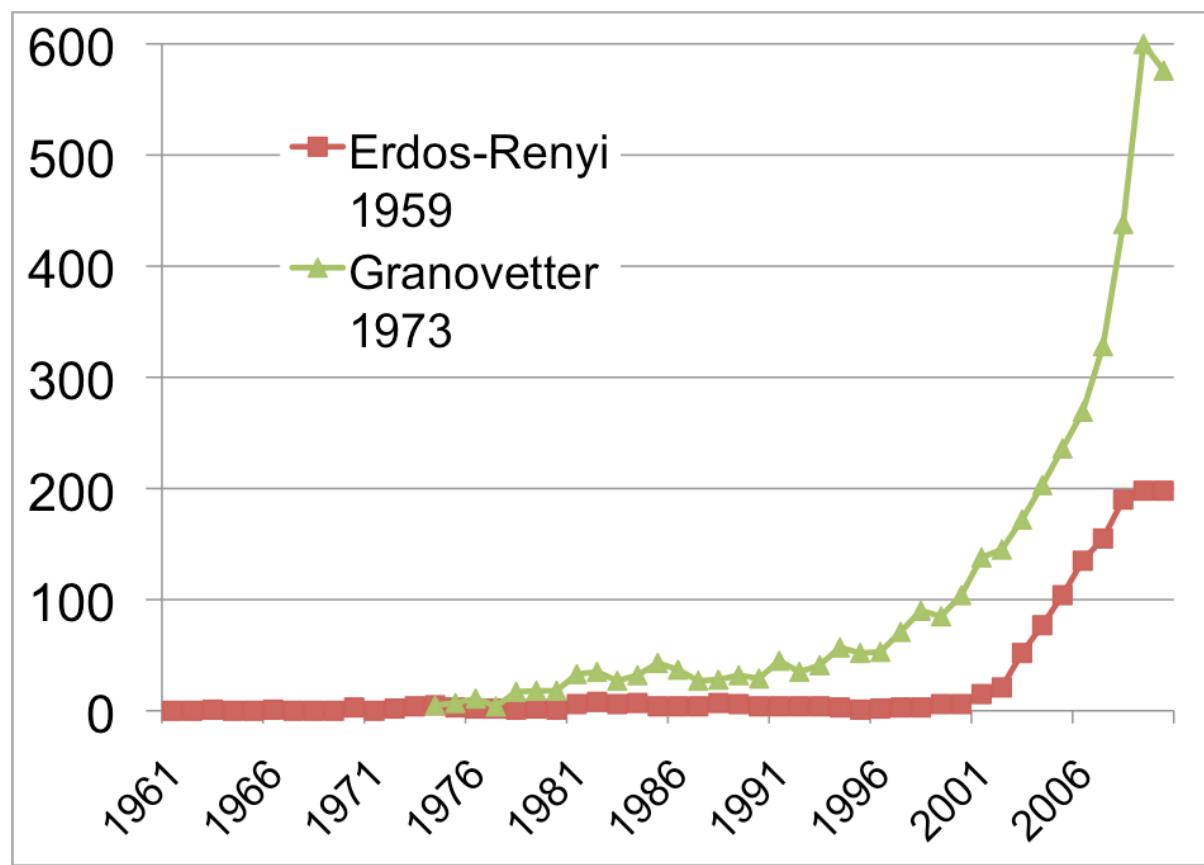
Communication networks:
1950s, Bavelas

Social networks:

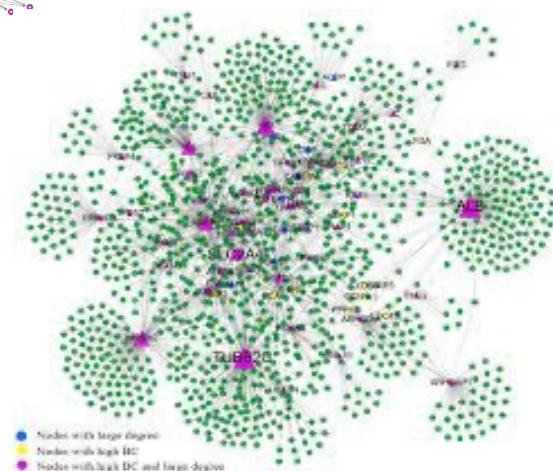
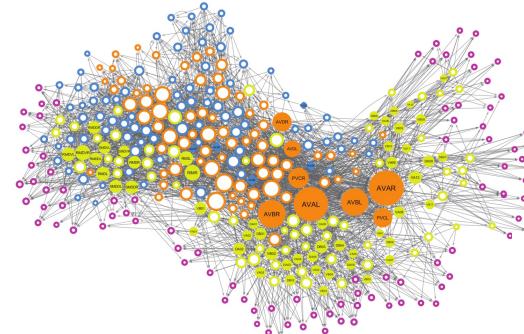
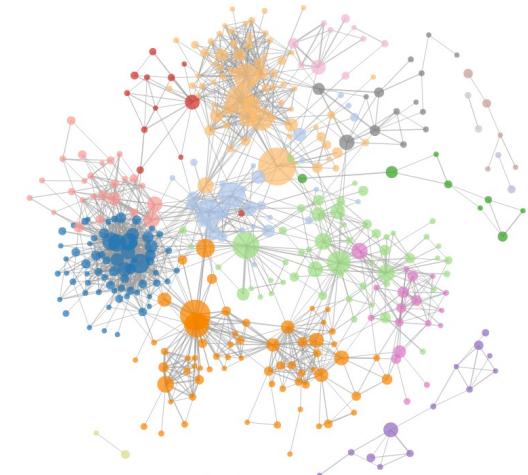
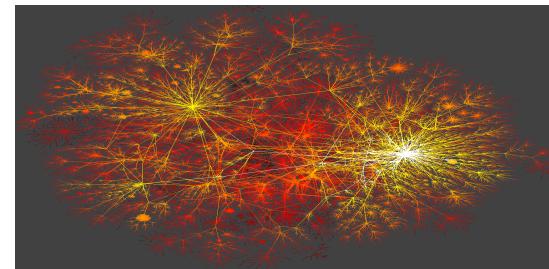
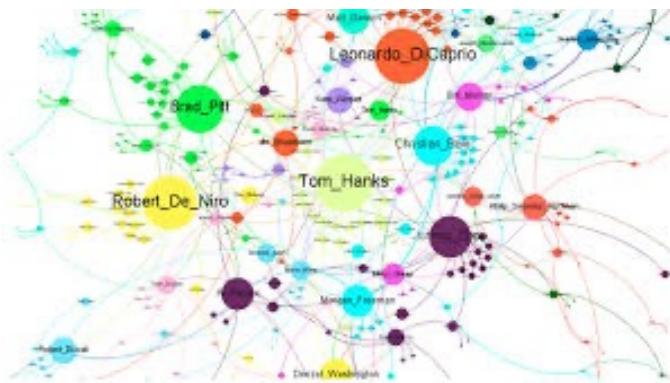
1930s, Moreno



Ecological networks:
1979, May



The emergence of large-scale network data:



Movie Actor Network, 1998;
World Wide Web, 1999.
C elegans neural wiring diagram 1990
Citation Network, 1998
Metabolic Network, 2000;
PPI network, 2001

- Nodes with large degree
- Nodes with high IC
- ▲ Nodes with high DC and large degree

The (surprising) **universality** of network characteristics

The architecture of networks emerging in various domains of science, nature, and technology are more similar to each other than one would have expected.

What is network science?

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational

Visual

Interdisciplinary

Empirical (data-driven)

Quantitative and Mathematical

Computational

Visual

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational

Visual

Interdisciplinary
Empirical
Quantitative and Mathematical

Computational

Visual

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational

Visual

THE IMPACT OF NETWORK SCIENCE

Or, so whats the big deal?

Economic impact



Google

Market Cap(Jan 1, 2023):
\$1.2 trillion

Cisco Systems

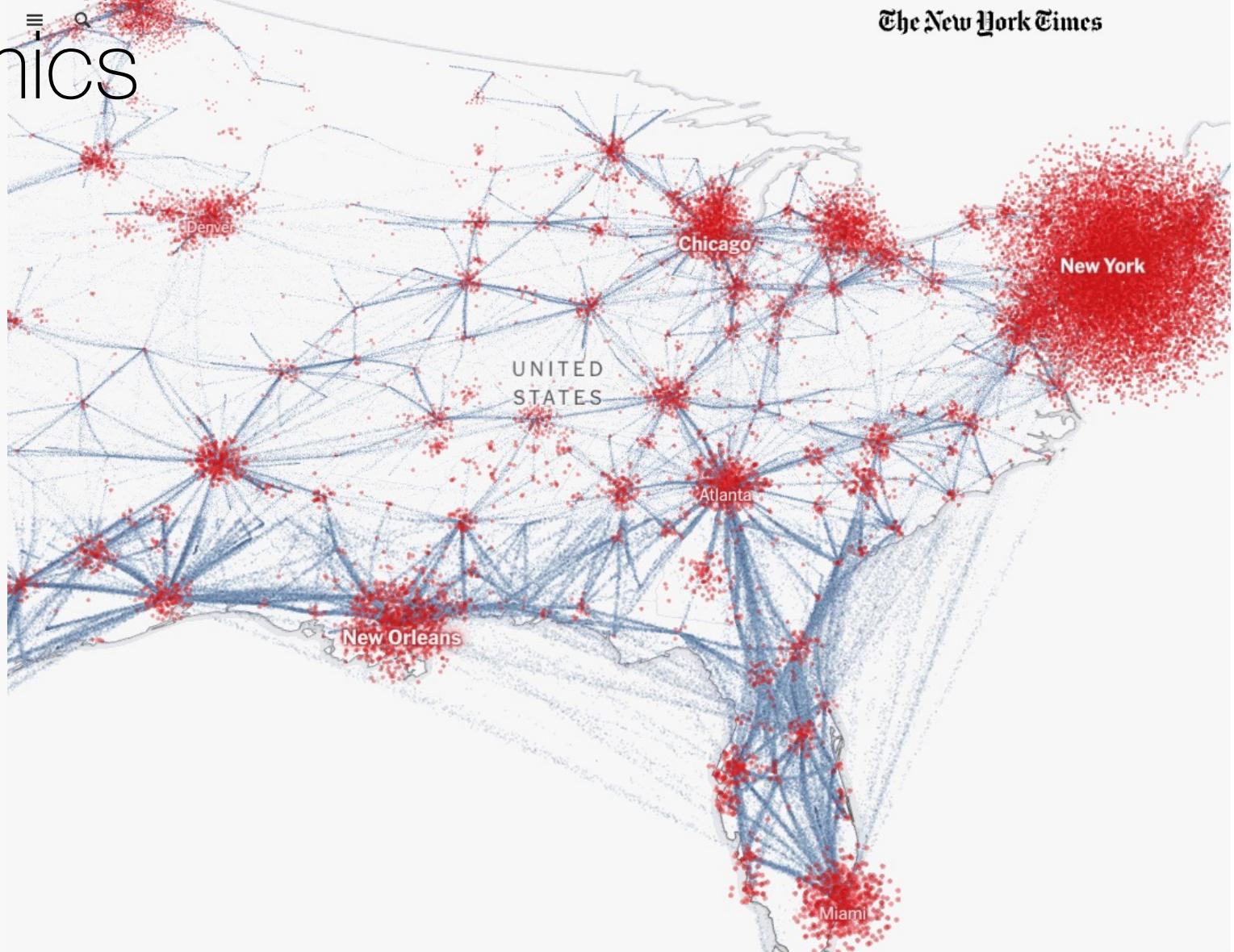
networking gear Market
cap (Jan 1, 2023):
\$192 billion

Facebook
market cap:
\$356 billion

Twitter
market cap:
\$41 billion

Epidemics

The New York Times



Genetic networks

nature
REVIEWS
SCIENTIFIC REVIEWS OF THE LITERATURE

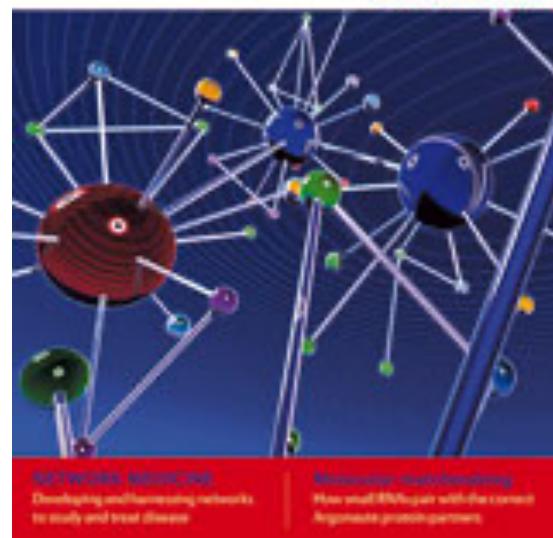
GENETICS



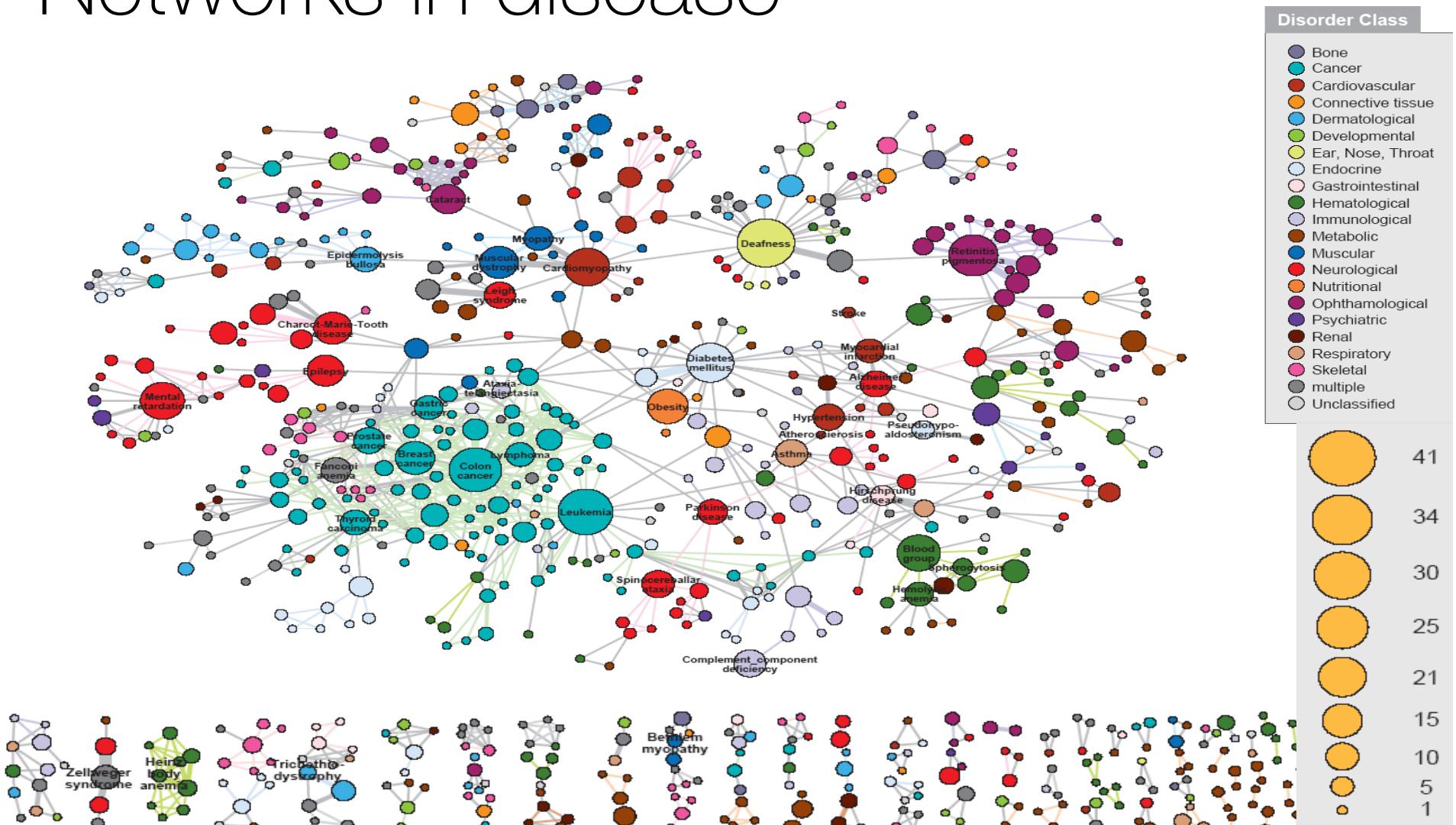
nature
REVIEWS

SCIENTIFIC REVIEWS OF THE LITERATURE

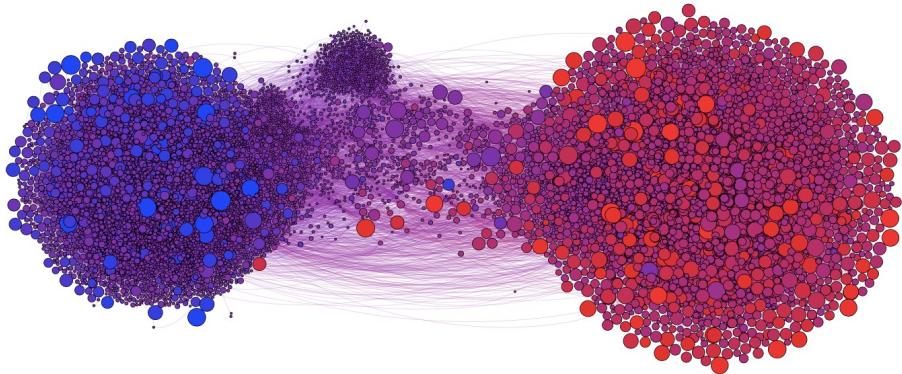
GENETICS



Networks in disease

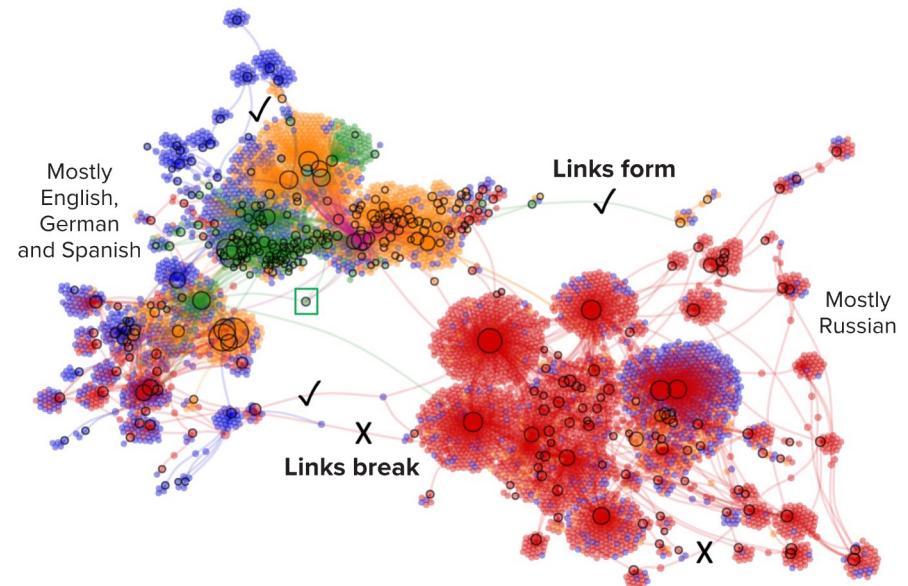


Spread of (mis)information



How hate spreads online

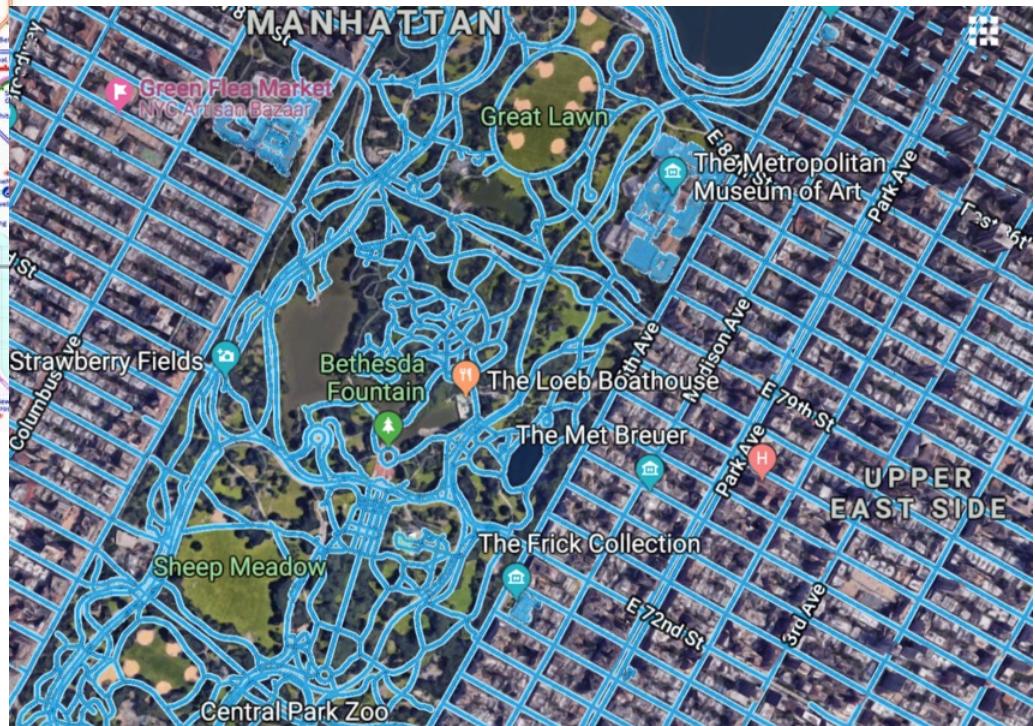
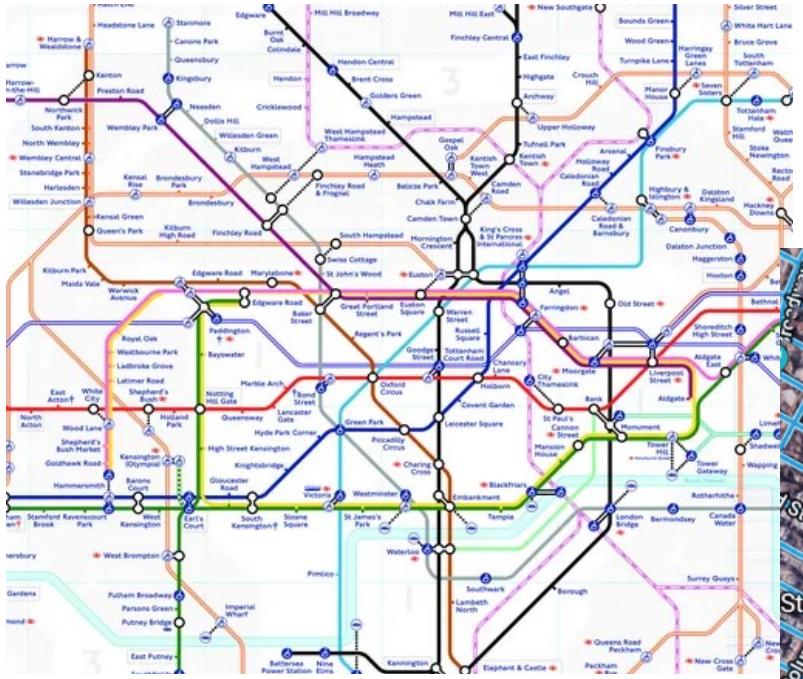
● 4Chan ● Facebook ● Gab.Social ● Instagram ● Telegram ● VKontakte



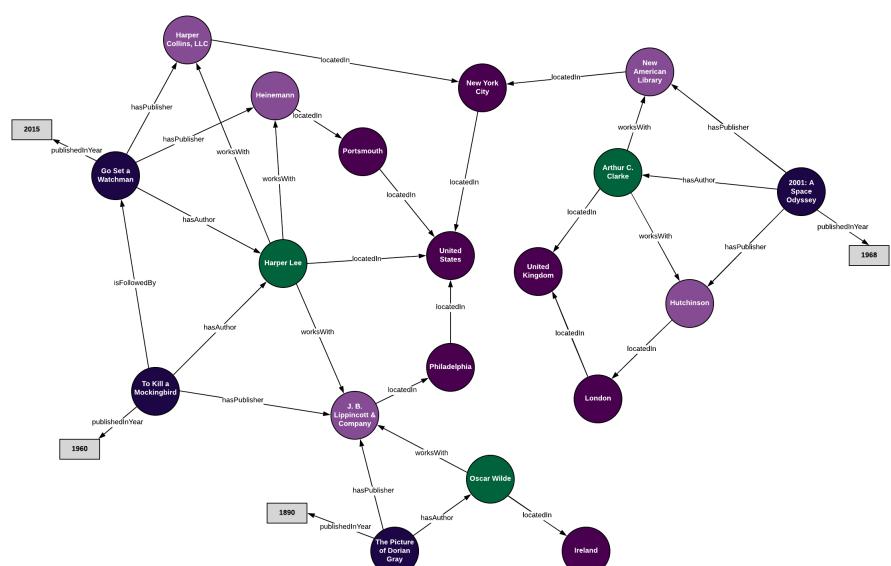
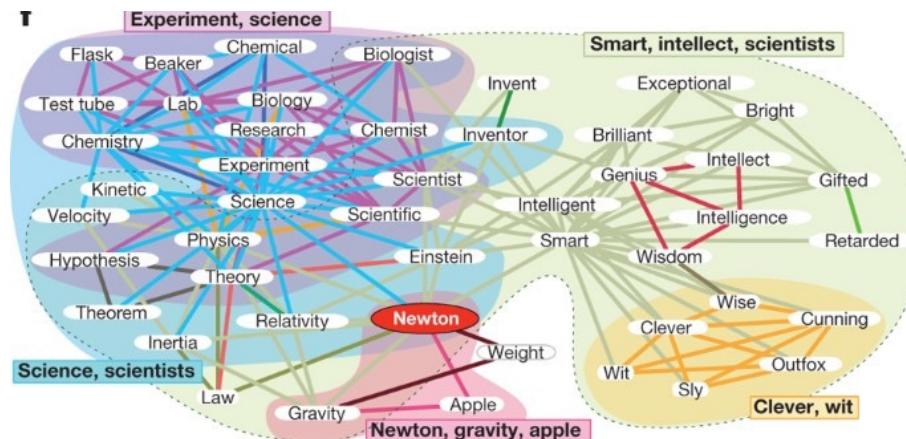
SOURCE: ADAPTED FROM N.F. JOHNSON ET AL / ARXIV: 2008.08513, 2020

KNOWABLE MAGAZINE

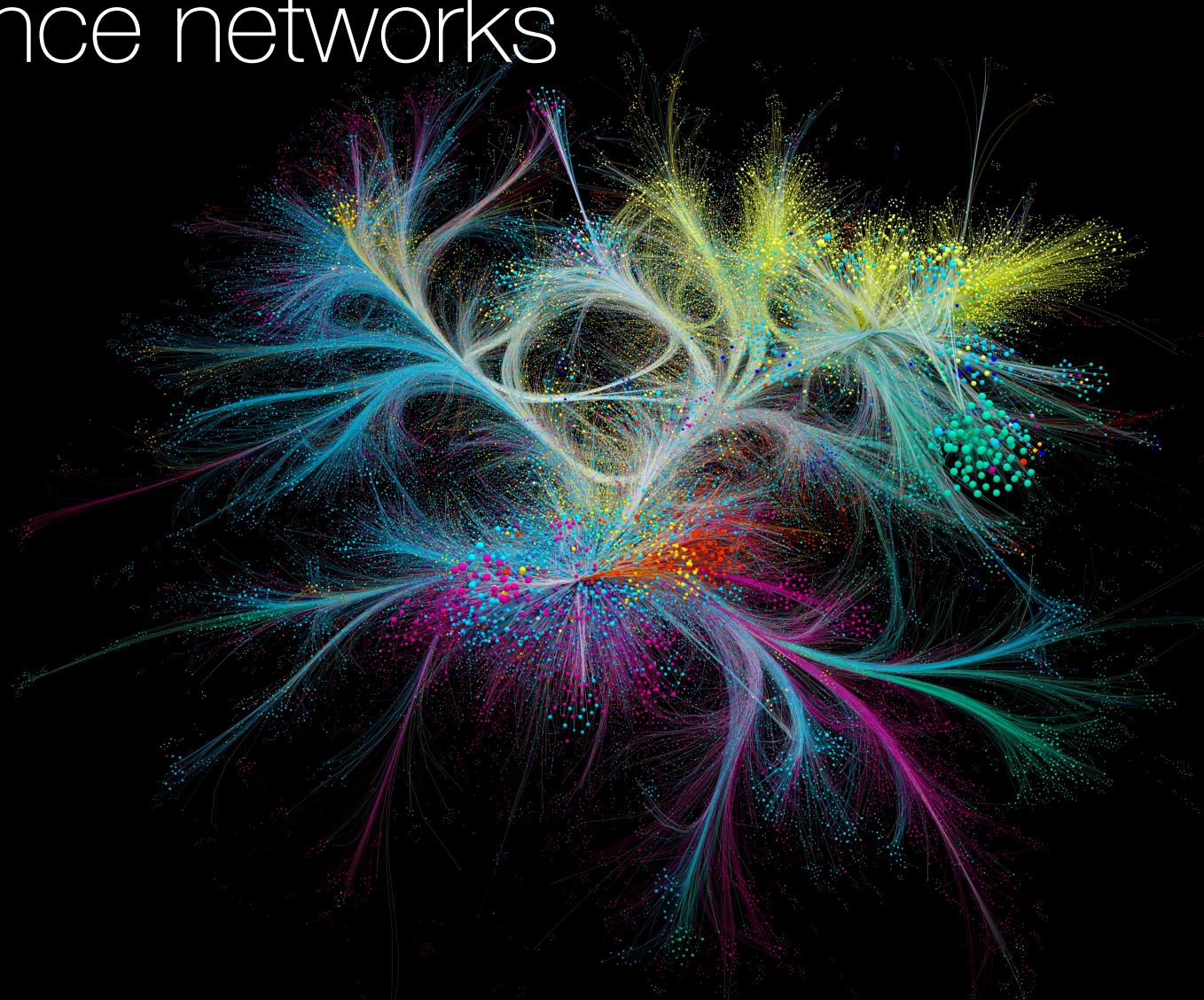
Transportation networks



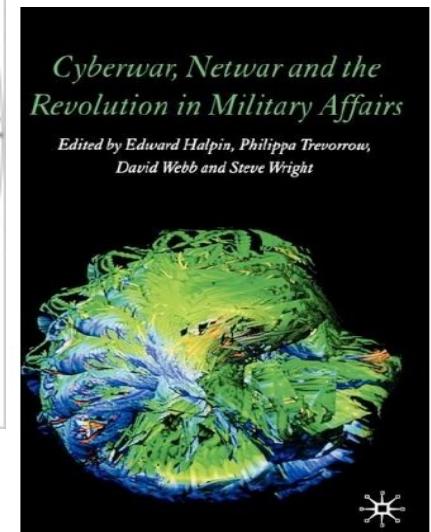
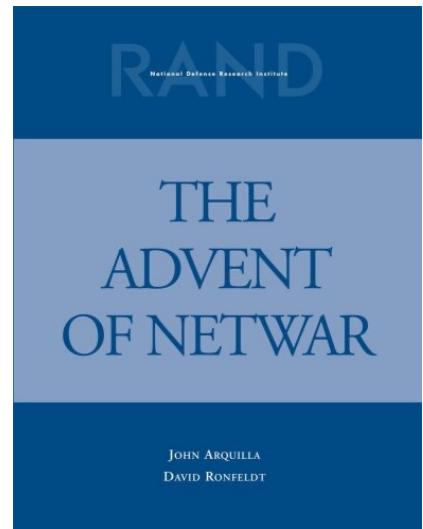
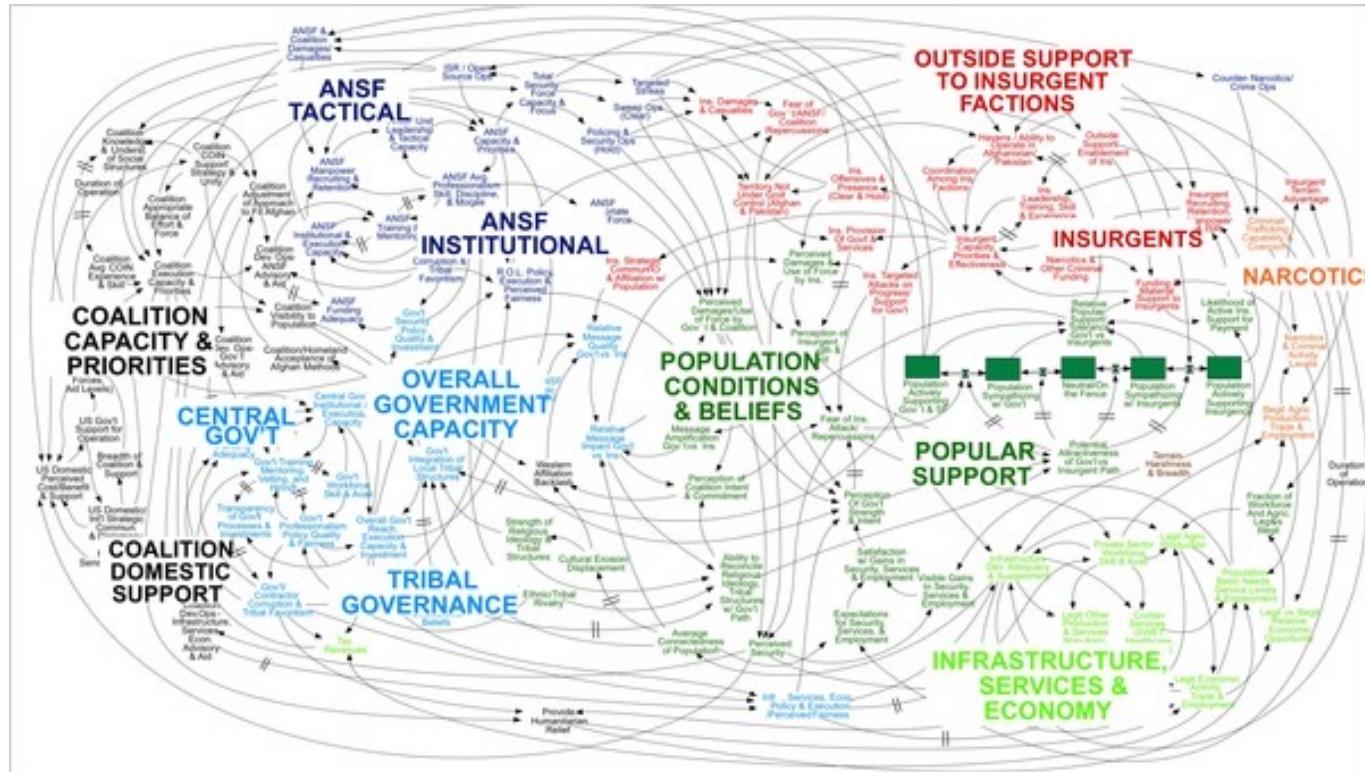
Knowledge graphs



Science networks



Military & cybersecurity



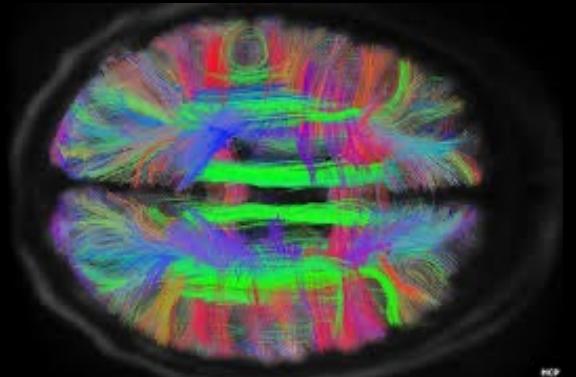
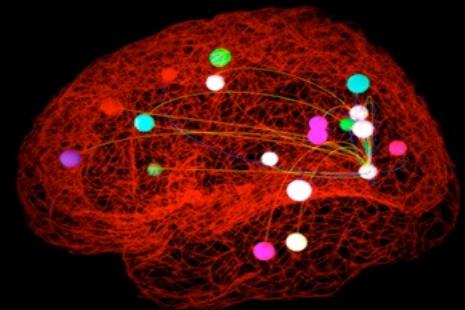
<http://www.slate.com/id/2245232>

Brain networks

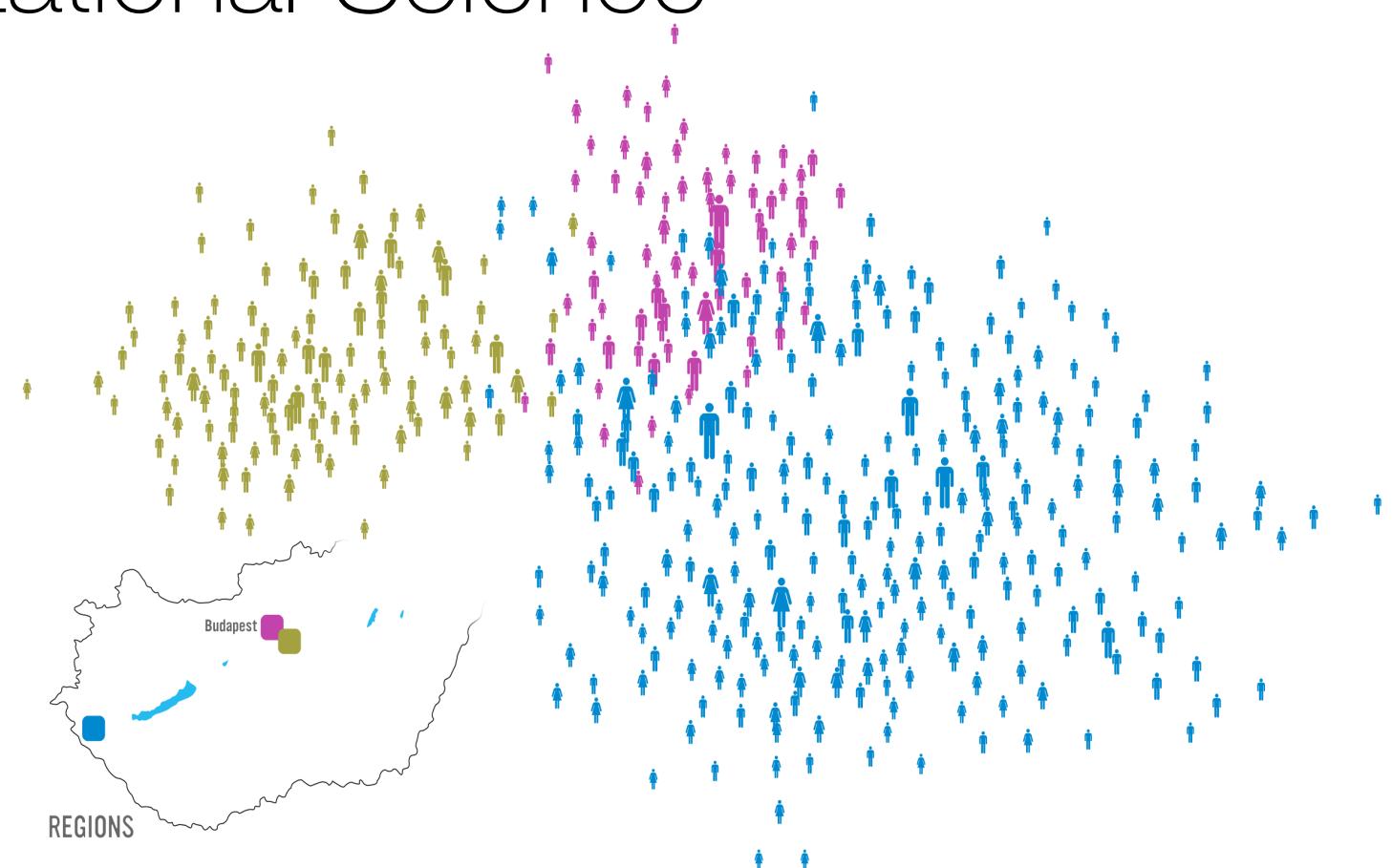
In September 2010 the National Institutes of Health awarded \$40 million to researchers at Harvard, Washington University in St. Louis, the University of Minnesota and UCLA, to develop the technologies that could systematically map out brain circuits.

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.

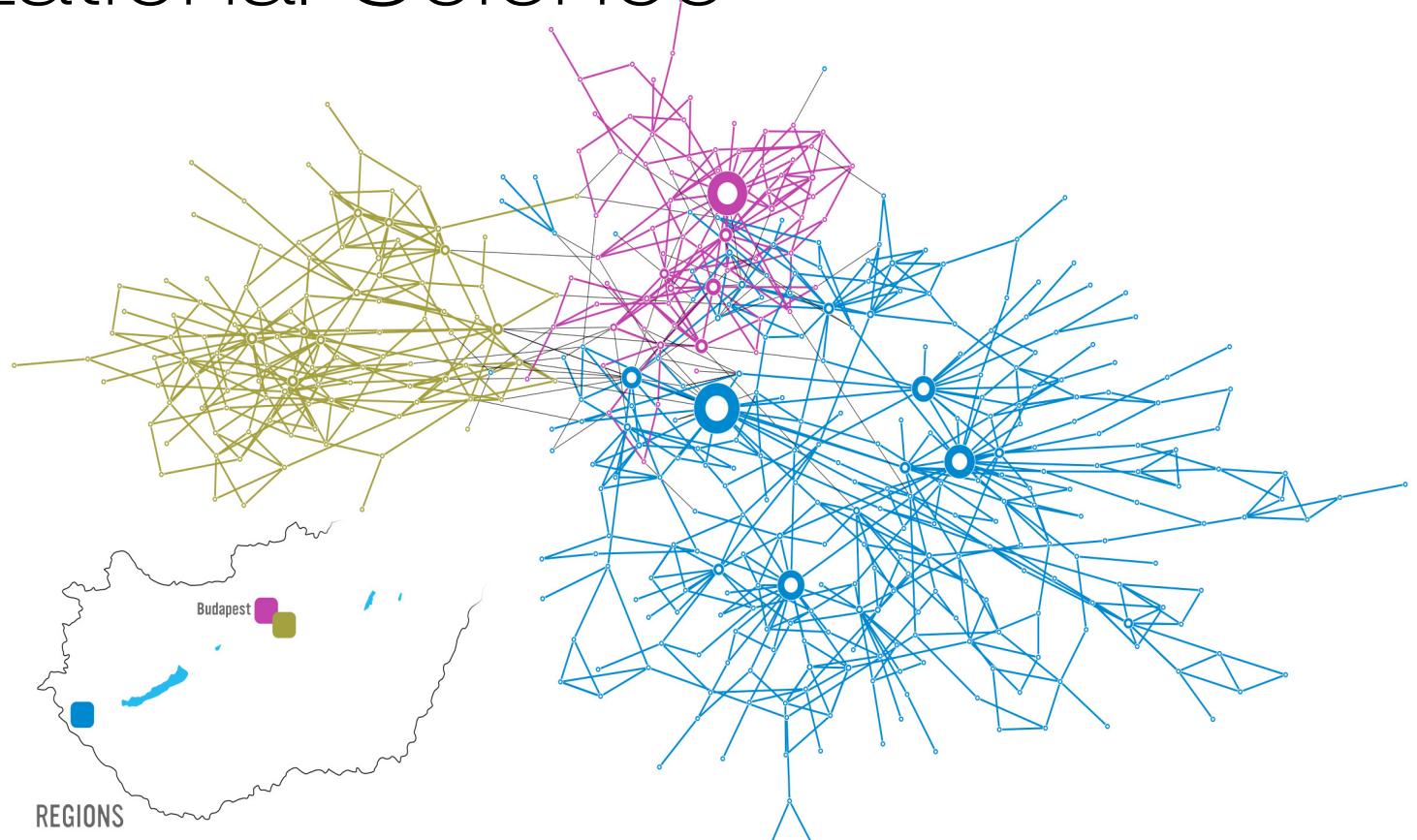
<http://www.humanconnectomeproject.org/overview/>



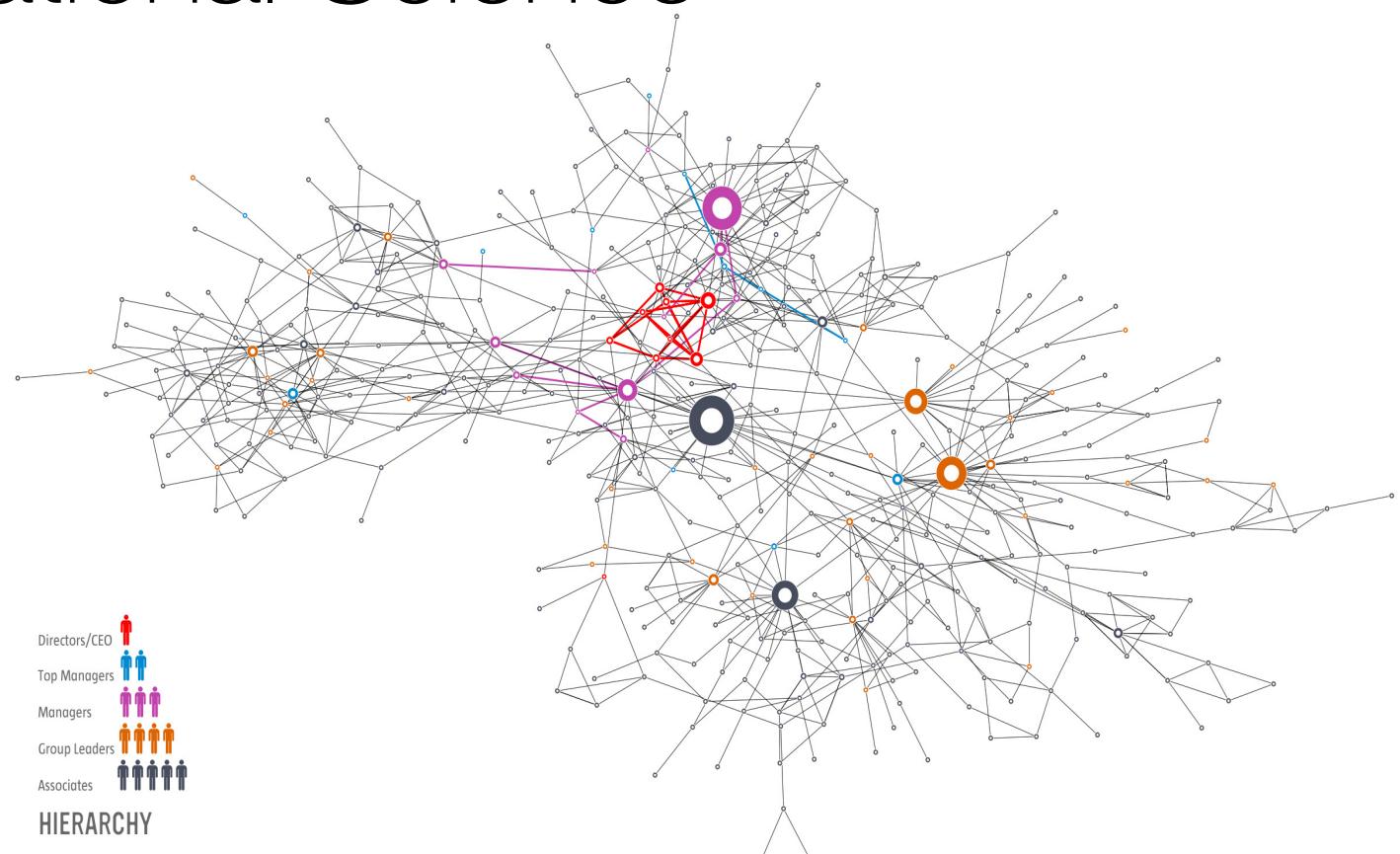
Management & Organizational Science



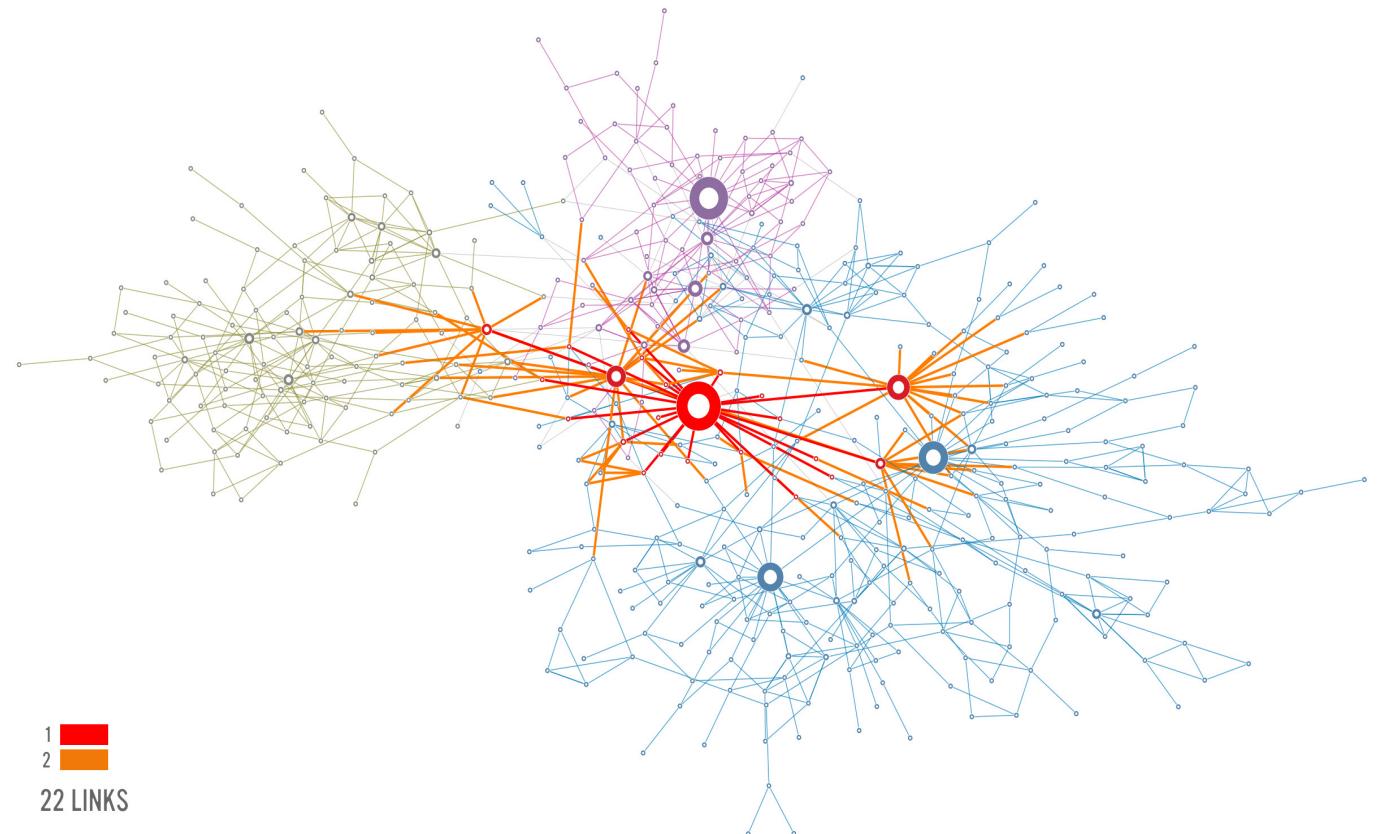
Management & Organizational Science



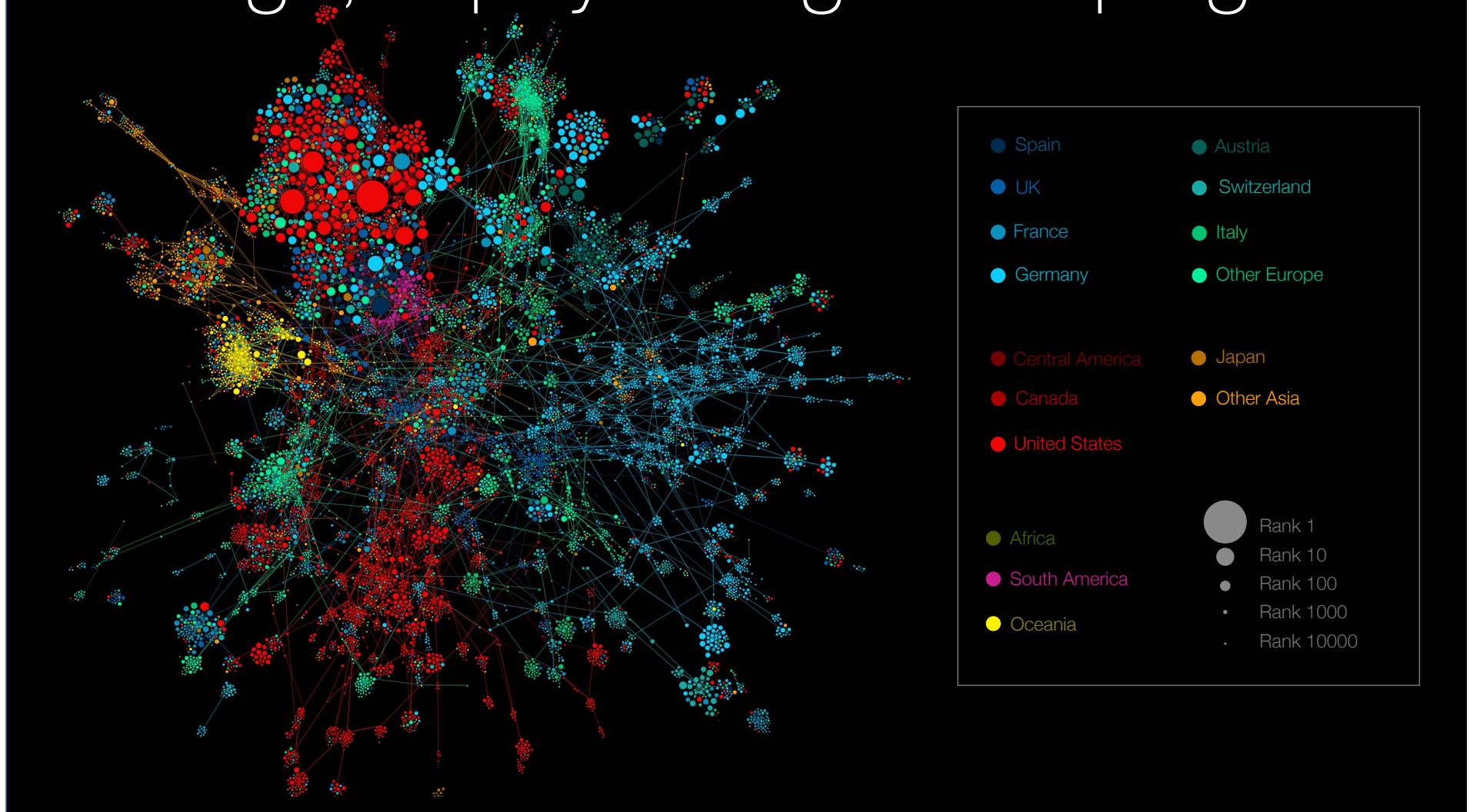
Management & Organizational Science



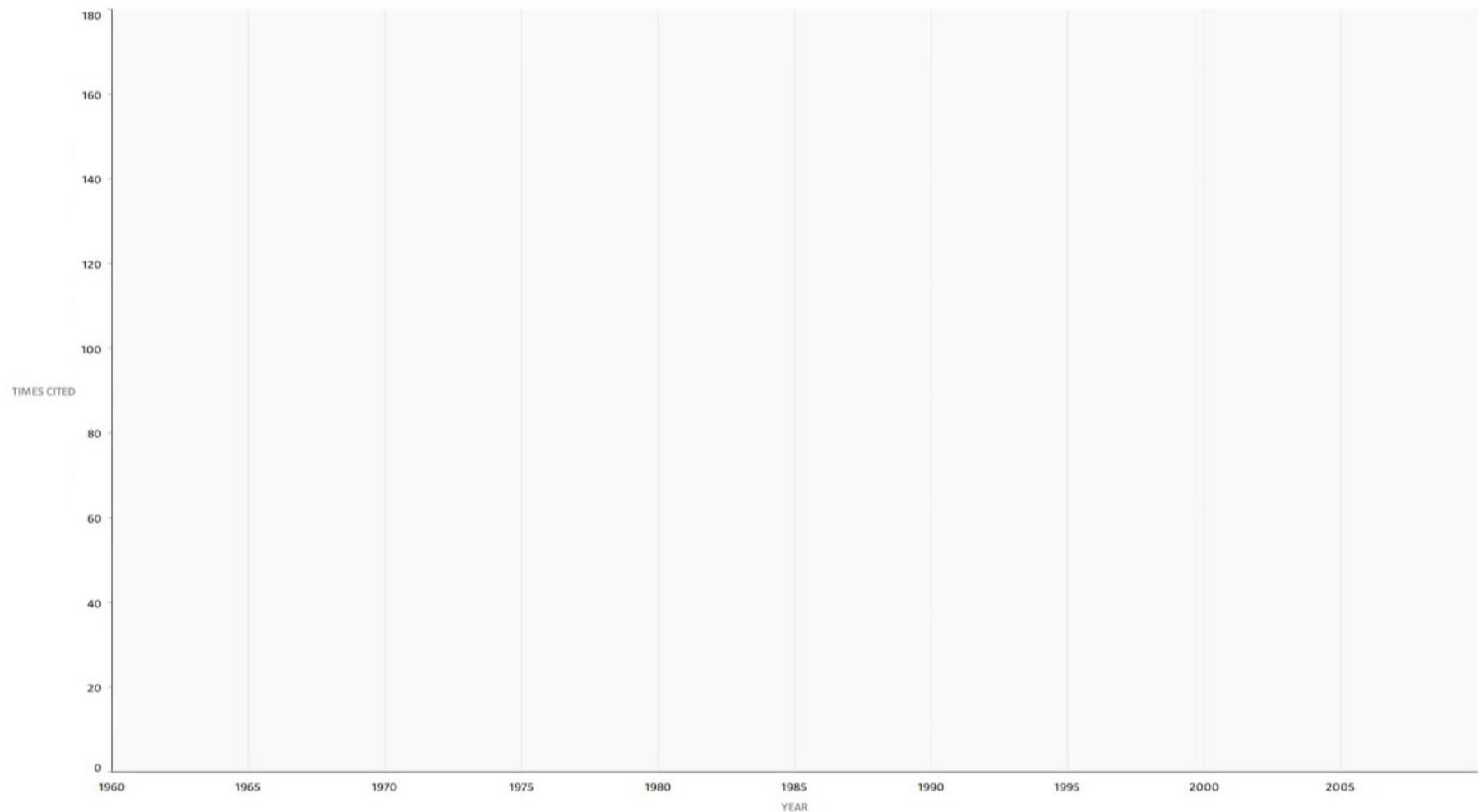
Management & Organizational Science



Prestige, equity and gatekeeping



SCIENTIFIC IMPACT



Collective dynamics of 'small-world' networks

Duncan J. Watts* & Steven H. Strogatz

*Department of Theoretical and Applied Mechanics, Kimball Hall,
Cornell University, Ithaca, New York 14853, USA*



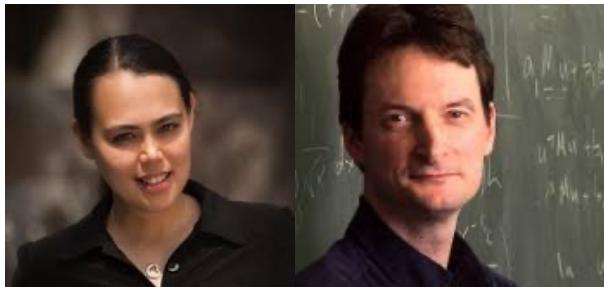
Emergence of Scaling in Random Networks

Albert-László Barabási* and Réka Albert



PHYSICAL REVIEW LETTERS

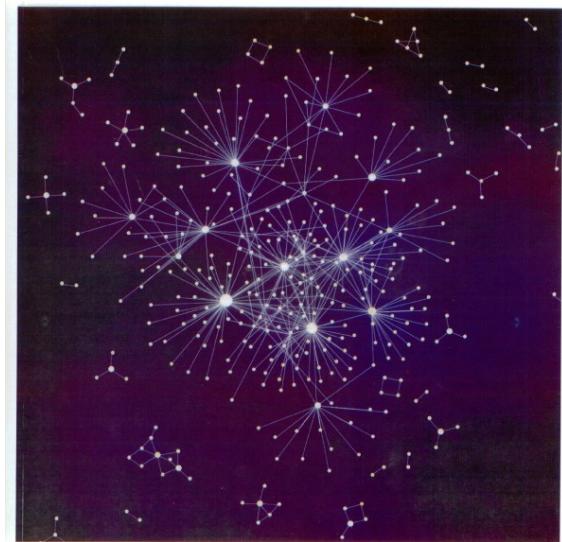
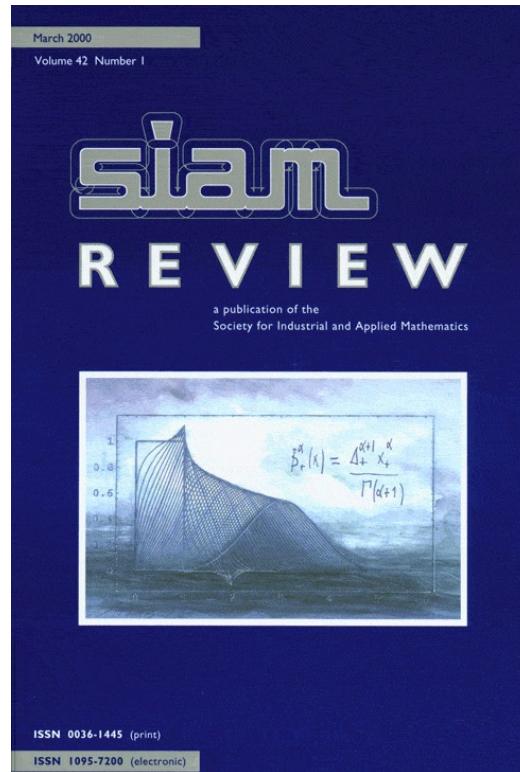
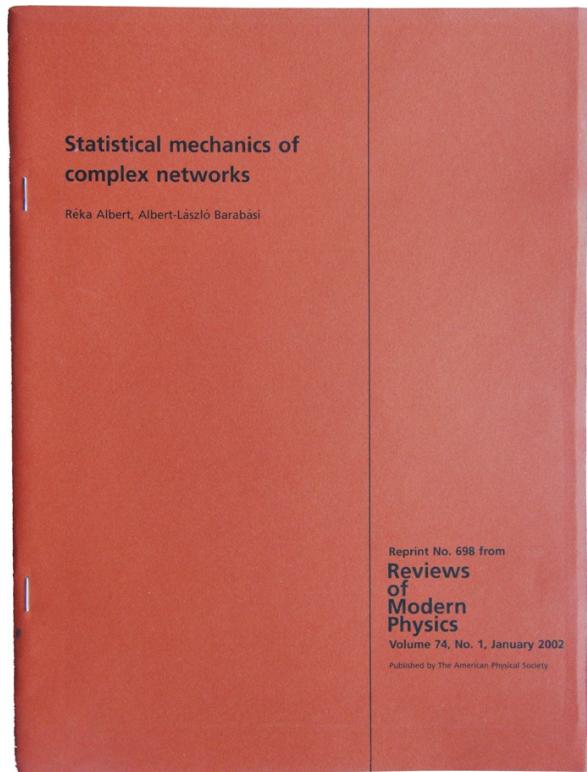
Epidemic Spreading in Scale-Free Networks

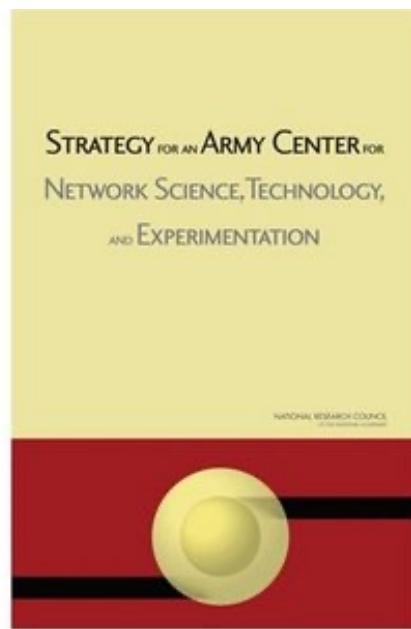
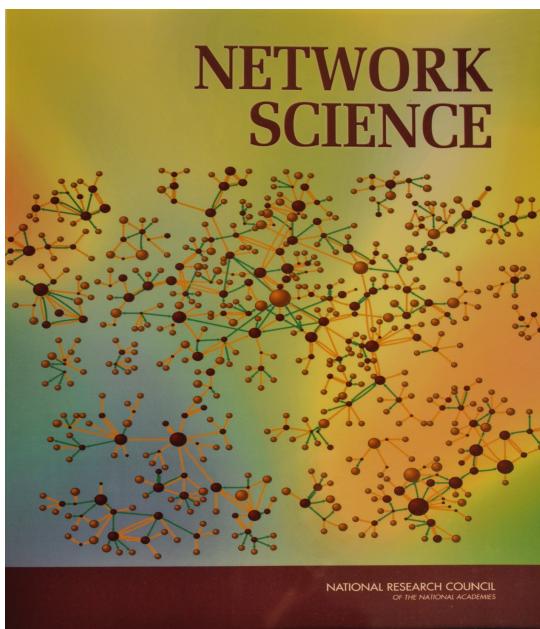


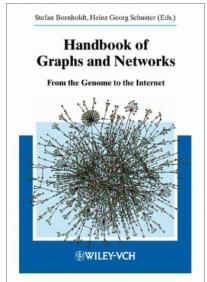
Community structure in social and biological networks

M. Girvan*†‡ and M. E. J. Newman*§

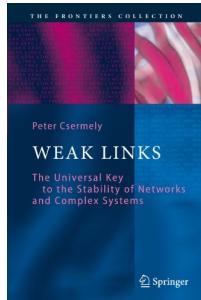
*Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501; †Department of Physics, Cornell University, Clark Hall, Ithaca, NY 14853-2501; and



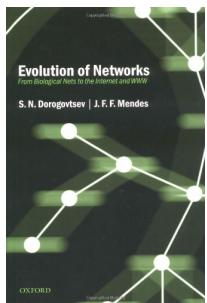




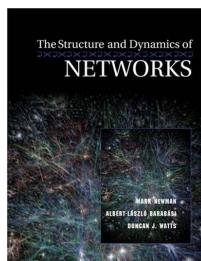
Handbook of Graphs and Networks: From the Genome to the Internet (Wiley-VCH, 2003).



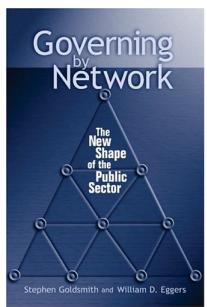
P. Csermely, Weak Links: The Universal Key to the Stability of Networks and Complex Systems (The Frontiers Collection) (Springer, 2006), 1st edn.



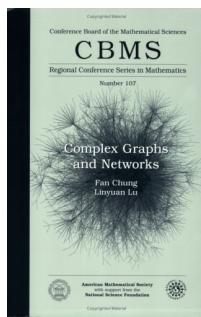
S. N. Dorogovtsev and J. F. F. Mendes, Evolution of Networks: From Biological Nets to the Internet and WWW (Oxford University Press, 2003).



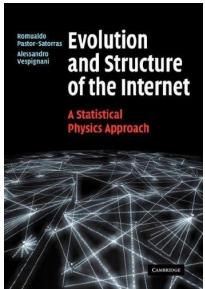
M. Newman, A.-L. Barabasi, D. J. Watts, The Structure and Dynamics of Networks: (Princeton Studies in Complexity) (Princeton University Press, 2006), 1st edn.



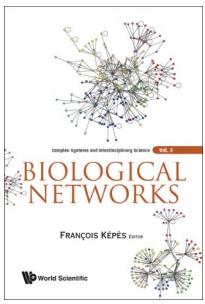
S. Goldsmith, W. D. Eggers, Governing by Network: The New Shape of the Public Sector (Brookings Institution Press, 2004).



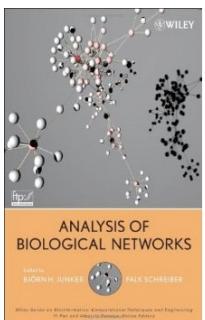
L. L. F. Chung, Complex Graphs and Networks (CBMS Regional Conference Series in Mathematics) (American Mathematical Society, 2006).



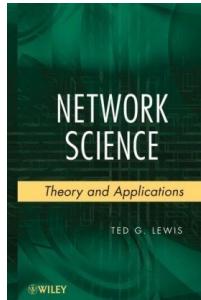
R. Pastor-Satorras, A. Vespignani, *Evolution and Structure of the Internet: A Statistical Physics Approach* (Cambridge University Press, 2007), 1st edn.



F. Képès, *Biological Networks (Complex Systems and Interdisciplinary Science)* (World Scientific Publishing Company, 2007), 1st edn.



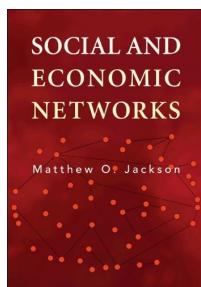
B. H. Junker, F. Schreiber, *Analysis of Biological Networks* (Wiley Series in Bioinformatics) (Wiley-Interscience, 2008).



T. G. Lewis, *Network Science: Theory and Applications* (Wiley, 2009).



E. Ben Naim, H. Frauenfelder, Z. Toroczkai, *Complex Networks (Lecture Notes in Physics)* (Springer, 2010), 1st edn.



M. O. Jackson, *Social and Economic Networks* (Princeton University Press, 2010).

How Everything Is Connected to
Everything Else and What It Means for
Business, Science, and Everyday Life

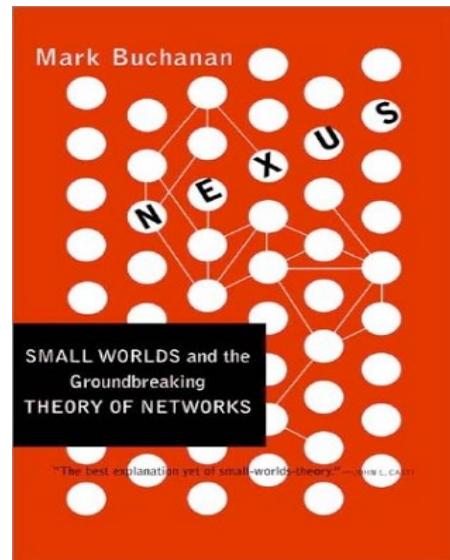
Linked



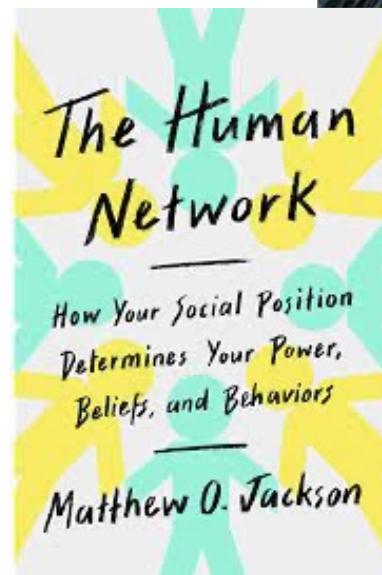
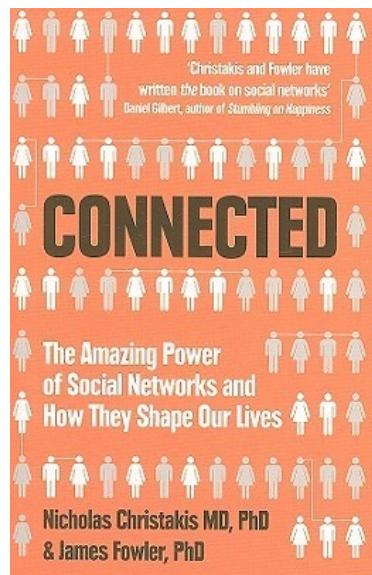
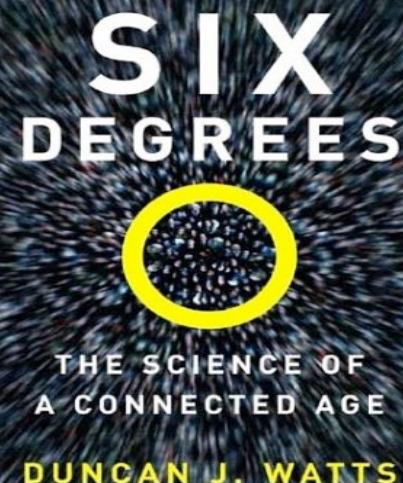
"*Linked* could alter the way we think about all of the networks that affect our lives." —*The New York Times*

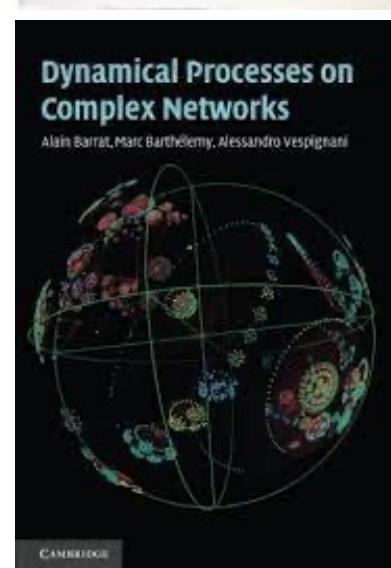
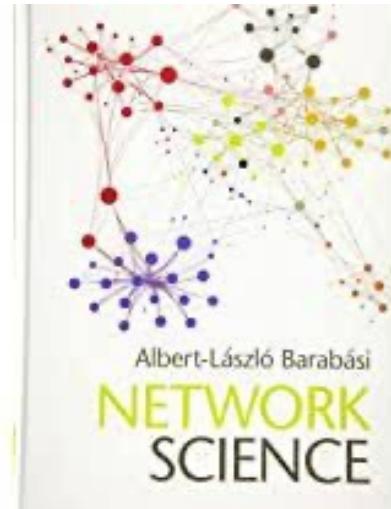
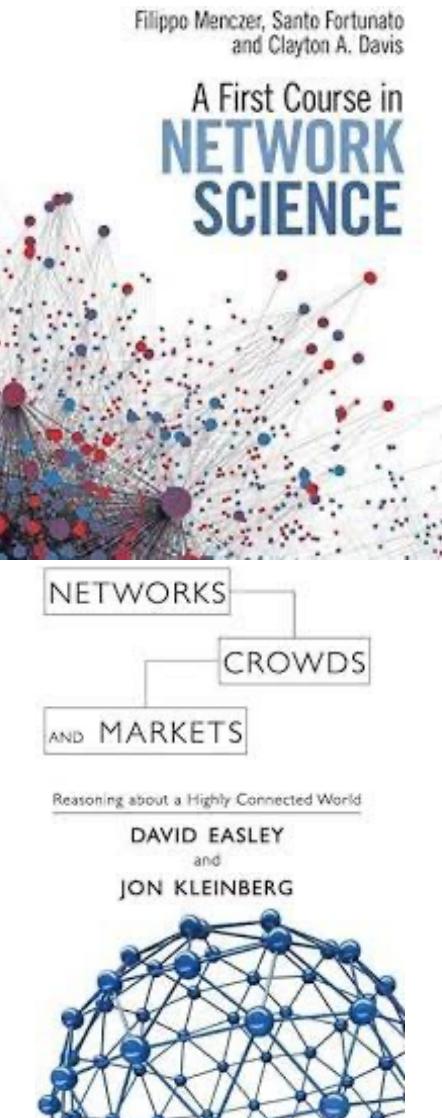
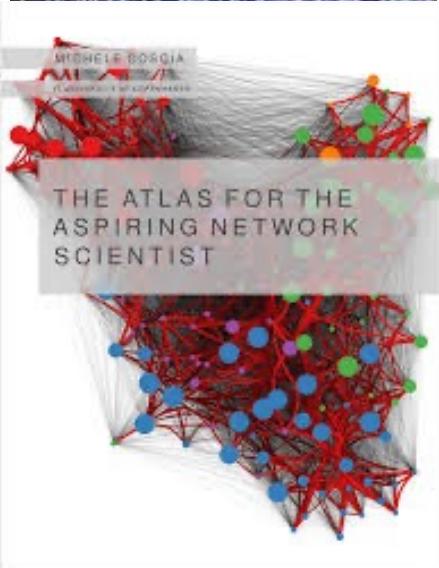
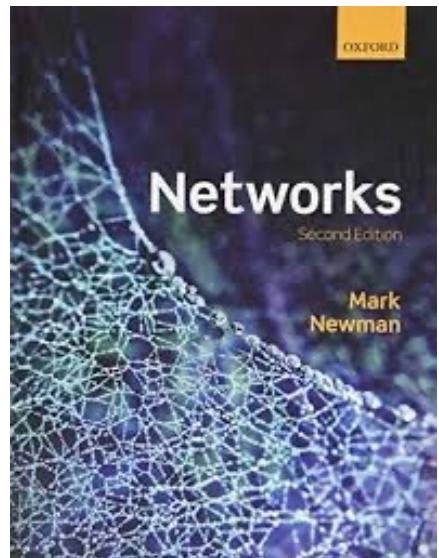
Albert-László Barabási

With a New Afterword



"This is a story that is both personal and remarkable for its ability to convey the wonder of complex science." —Bill Miller, CEO of Legg Mason Funds, Inc.







CLASS INFORMATION



Network Science

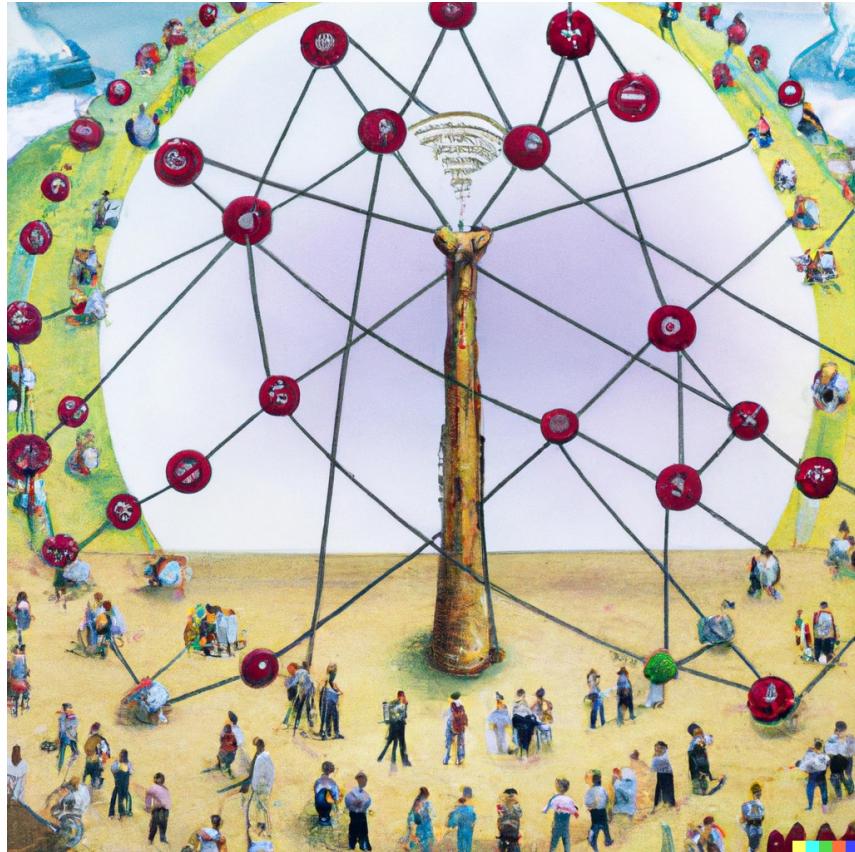
Making connections from complex data

DS 8104 – Spring 2023
School of Data Science
University of Virginia



<https://uvads8104.github.io/>

Course format



Classes: Tu,Th 2:00-3:15pm

In person:
Elliewood Conference Room

Deliverables:

(50%) Weekly article
discussion & participation

(50%) Class project

Learning Goals

Develop a **network intuition** for reasoning about system behavior

Understand network representations, terminology, and concepts

Analyze and model real-world **network data**



Check the syllabus on the course website!
<https://uvads8104.github.io>

First Assignment

Read the syllabus on the course website!

<https://uvads8104.github.io>





Network Science

Making connections from complex data

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