Frontiers of Network Science
Fall 2024

Class 1: Introduction
(Chapter 1 in Textbook)

Boleslaw Szymanski

based on slides by Albert-László Barabási & Roberta Sinatra

Course CSCI-6250/4250 4cr: Frontier of Network Science
Monday - Thursday 12:00 - 13:40, Amos Eaton 216

Class Web-site
http://www.cs.rpi.edu/~szymansk/fns.24/index.php

Instructor: Prof. Boleslaw K. Szymanski, email: szymab@rpi.edu

Teaching Assistant: Vijay, Sadashivaiah e-mail: sadasv2@rpi.edu

Office Hours: Monday & Thursday, 15:00 – 16:00 by appointment by email either in the office (TBA) or by Webex link: https://rensselaer.webex.com/meet/sadasv2

Textbooks
Albert Laszlo Barabasi ***Network Science,*** Cambridge University Press, 2016
Available online at *http://barabasi.com/networksciencebook/*

In addition, class notes will be used.

Course Description

This course offers an introduction to Network Science and a review of current research in this field. Classes will interchangeably present chapters from the textbook and the related current research. The emphasis will be on the mathematical background of network science: graphs and networks; random networks and various types of scale-free networks; and on network properties such as assortativity, mobility, and robustness; social networks and communities; and dynamics of processes on networks.

Course Content

- Mathematical background of network science: graphs and networks.
- Random networks and their properties.
- Scale-free networks, small world networks and Barabasi-Alert model.
- Mobility and networks
- Network robustness
- Social networks and communities
- Assortativity of networks
- Dynamic processes

Grading Criteria

Undergraduates:

One individual programming homework (40% of the total grade), followed by **one individual presentation** of the selected research paper or textbook problem (50% of the total grade), with questions and participation in discussions for at least two student presentations will providing the remaining (10%) of the total grade.

The programming homework will be handed out approximately after the end of the 4th week, together with choices of networks for experiments, and due in three weeks after that. The homework will require using network analysis tools (or programming) and analysis of the results obtained for the real and synthetic networks. The graded homework will be returned to undergraduates approximately one week after they are handed in. Students will have these grades as their means to determine progress in the course by mid-semester.

Students need to choose a topic for research and presentation either from the list of problems associated with the textbook or from the seminal papers that need to be approved by the instructor by the 7th week. The 25 min in class presentation + 5 min discussion of the assigned topic will be scheduled starting at the end of October.

Grading Criteria

Graduates:

Students will choose a topic for research and presentation either from the list of the seminal papers, or from their own current work, and approved by the instructor during the first two weeks of the class.

Around 6th week of the course, the research plan will be due of 3-5 pages defining the project part of the presentation on which research will be based (20%).

The 45 min presentation of the length of typical research length, followed by 5 min discussion will be due to be presented and delivered starting at the end of October (50%).

A written report of 8-12 pages due at the last class (20%). The remaining 10% of the grade will be assigned based on participation in discussions of the presentations.

Grade range for both graduates and undergraduates:
A 96. A- 91, B 85, B- 80, C 70, C- 60, F <60.

Student Learning Outcomes

Student Learning Outcomes:

Upon completion of this course, all students will be able to:

1. Apply fundamental network science ideas to create models and understand dynamics of networked systems;
2. Compare, contrast, and describe the similarities and differences of different kinds of networks and processes modeled on networks;
3. Critique the strengths and weaknesses of each of the models and types of networks based on them and these network types performance in diverse network science applications;
4. Understand the principles of applying network science to disciplinary science and design and set up basic models for some specific applications.

Additionally, graduate students will also be able to:

1. Read, analyze, and critique published literature in the field of network science and social networks;
2. Assess novelty of network science research and its relation to the state of the art in the field.

Course Assessment Measures

Undergraduates: Students' performance will be measured using three different methods:

(i) Programming homework

(ii) After selection of a current research paper or textbook problem for presentation, students will presentation the selected papers, including their content, and evaluate their scientific results.

(iii) Contributions to in-class discussions

The programming homework and presentation plans will measure the student's ability to apply concepts of network science to networks analysis.

The presentation and discussion of the paper results will measure student's ability to prepare summary material based on fundamental scientific concepts and basic research.

In-class discussion will measure students' ability to express their views at group meetings.

Graduates: Again, students' performance will be measured using three different methods:

(i) After selection of a current research paper or own research for presentation, students will presentation the selected topics, including content, and evaluate their scientific results.

(ii) Contributions to in-class discussions

(iii) Independent and novel mini-project on the topic of the presentation using different data, or methods.

The first two methods are the same as undergraduate methods (i) and (iii), while the third method assesses students' ability to apply network science tools to novel problems

Academic integrity:

Student-teacher relationships are built on trust. For example, students must trust that teachers have made appropriate decisions about the structure and content of the courses they teach, and teachers must trust that the assignments that students turn in are their own. Acts, which violate this trust, undermine the educational process. The Rensselaer Handbook of Student Rights and Responsibilities defines various forms of Academic Dishonesty and all students should make themselves familiar with these forms to avoid them.

In this class, all assignments that are turned in for a grade must represent the student's own work. Submission of any assignment that is in violation of this policy will result in a penalty of 0 points for assignment and failing of the course in case of repetition.

If you have any question concerning this policy, please ask for clarification before preparing or submitting an assignment or making a presentation.

Use of AI tools

A summary of policy proposed by Ethan Mollick from the University of Pennsylvania

Tools like AI, e.g., ChatGPT, and image generators, e.g., Gephi, are allowed in this class since learning to use AI is an emerging skill. Be aware of the limits of ChatGPT:

1. If you provide minimal prompts, you may get low-quality results. Be prepared to enrich your prompts to get good outcomes.
2. Refrain from trusting anything ChatGPT says. Check the numbers and facts provided by it. You will be responsible for any errors or omissions the tool offers.
3. You also must acknowledge its use. This acknowledgment should include a paragraph at the end of any AI-assisted assignment explaining what you used the AI for and listing
4. the prompts you used. Failure to do so is a severe violation of academic honesty policies.

Please include a paragraph at the end of any assignment that uses AI explaining what you used the AI for and what and list prompts that you used. Please do so to uphold the academic honesty policies.

Attendance Policy:

Attendance in classes is in general not required but it is recommended because the material presented in classes includes topics beyond the textbook.

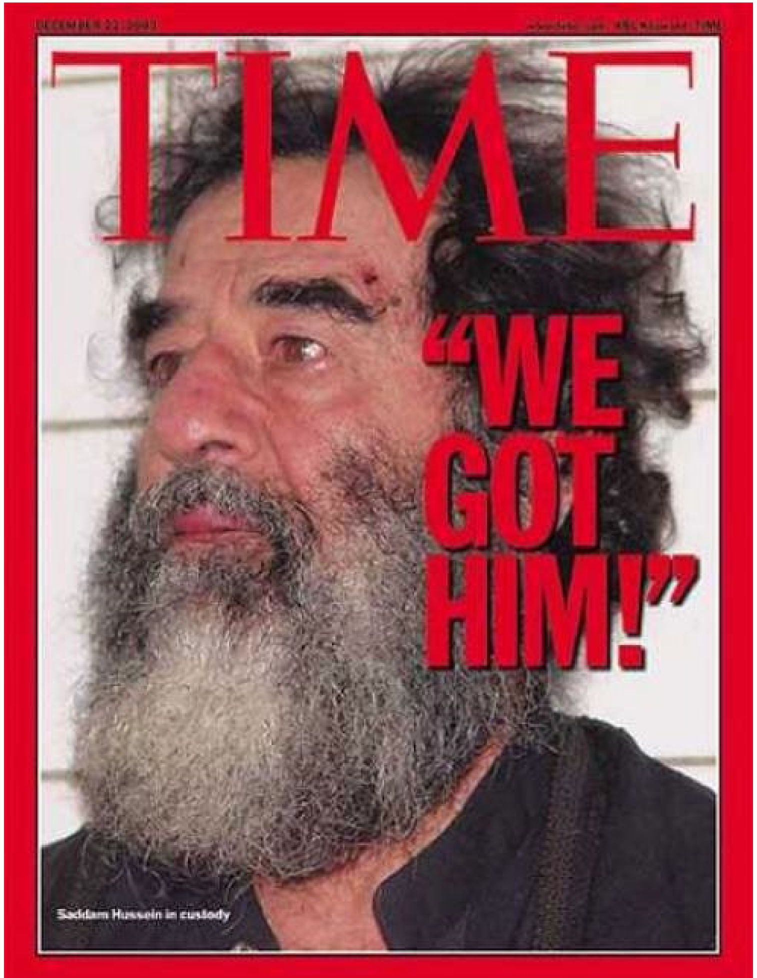
However, the attendance and active participation is required in at least two research presentations with active participation is needed to receive score for active participation.

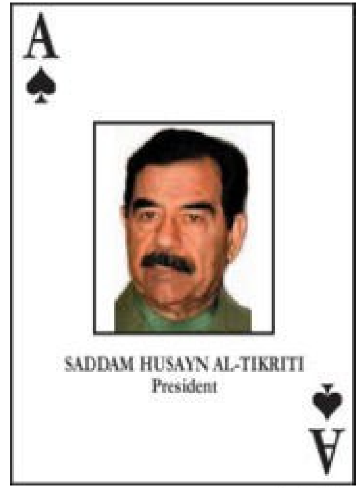
Missed deadline for homework, unless justified by medical or personal reasons and approved by instructor, will lower the achieved score by 10% for each week of delay.

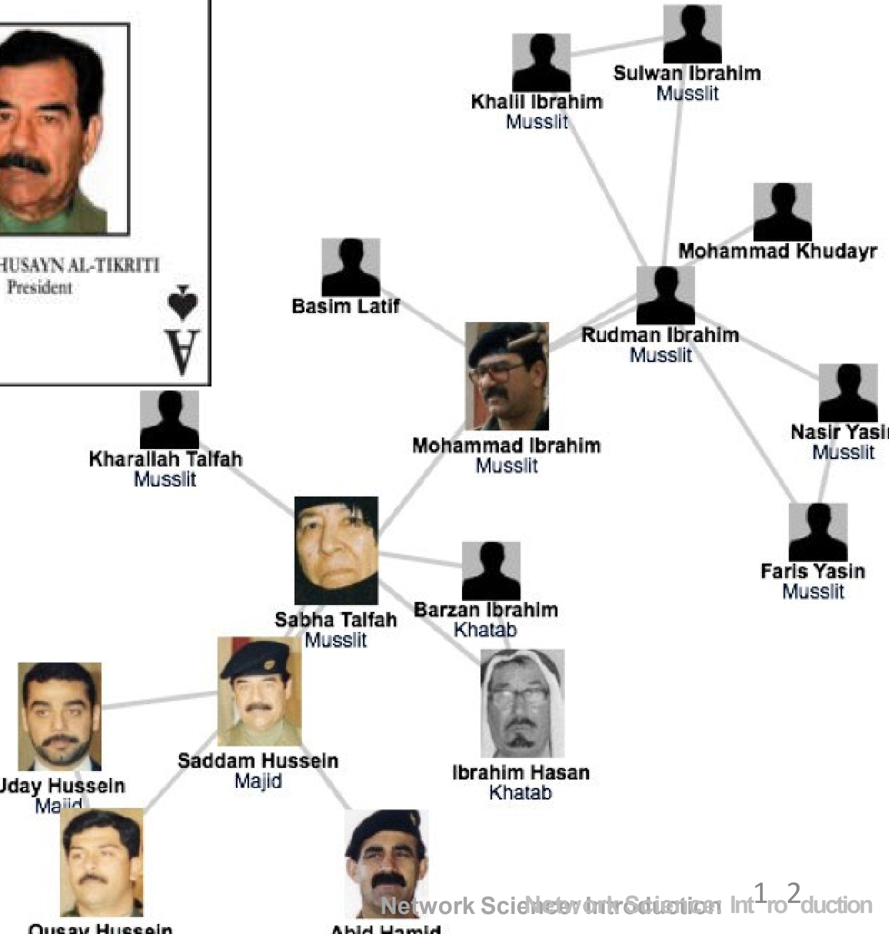
Presentations can be rescheduled but only in emergencies.

FROM SADDAM HUSSEIN TO NETWORK THEORY

A SIMPLE STORY (1) The fate of Saddam and network science







A SIMPLE STORY (1) The fate of Saddam and network science

The capture of Saddam Hussein:

→shows the strong predictive power of networks.

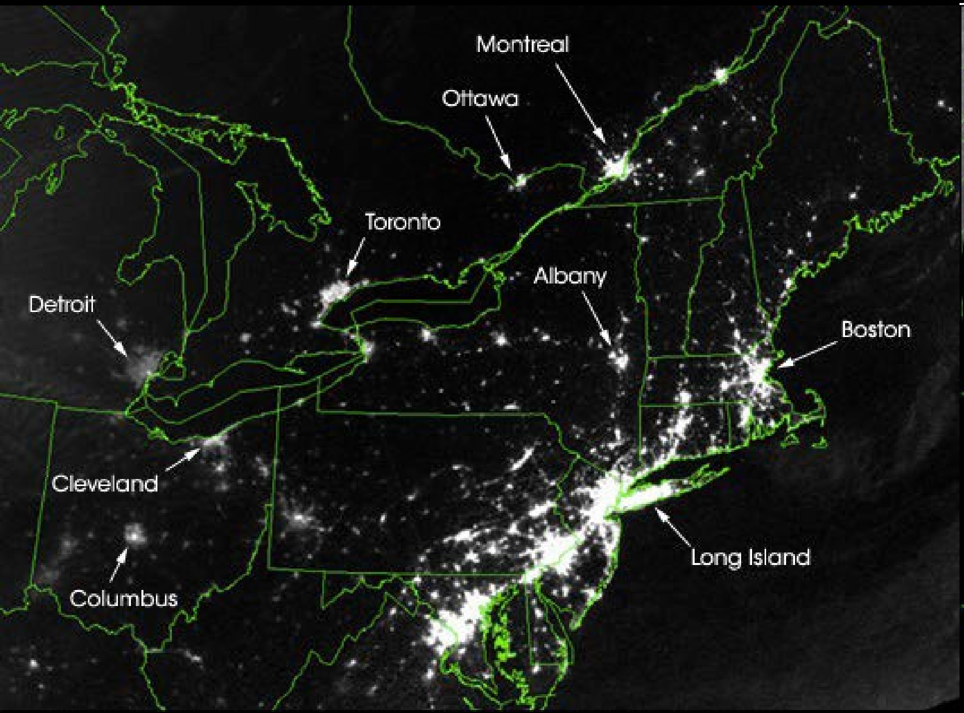
→ underlies the need to obtain accurate maps of the networks we aim to study; and the often heroic difficulties we encounter during the mapping process.

→ 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.

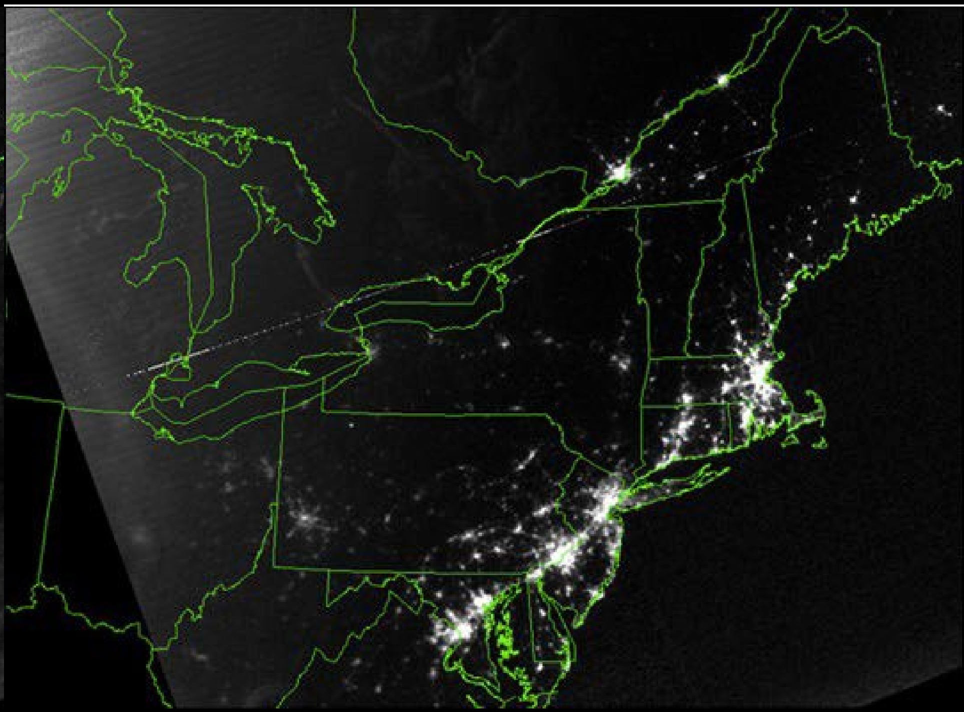
→ shows that the choice of network we focus on makes a huge difference: the hierarchical tree, that captured the official organization of the Iraqi government, was of no use when it came to Saddam Hussein's whereabouts.

VULNERABILITY DUE TO INTERCONNECTIVITY

A SIMPLE STORY (2): August 15, 2003 blackout.



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



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

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

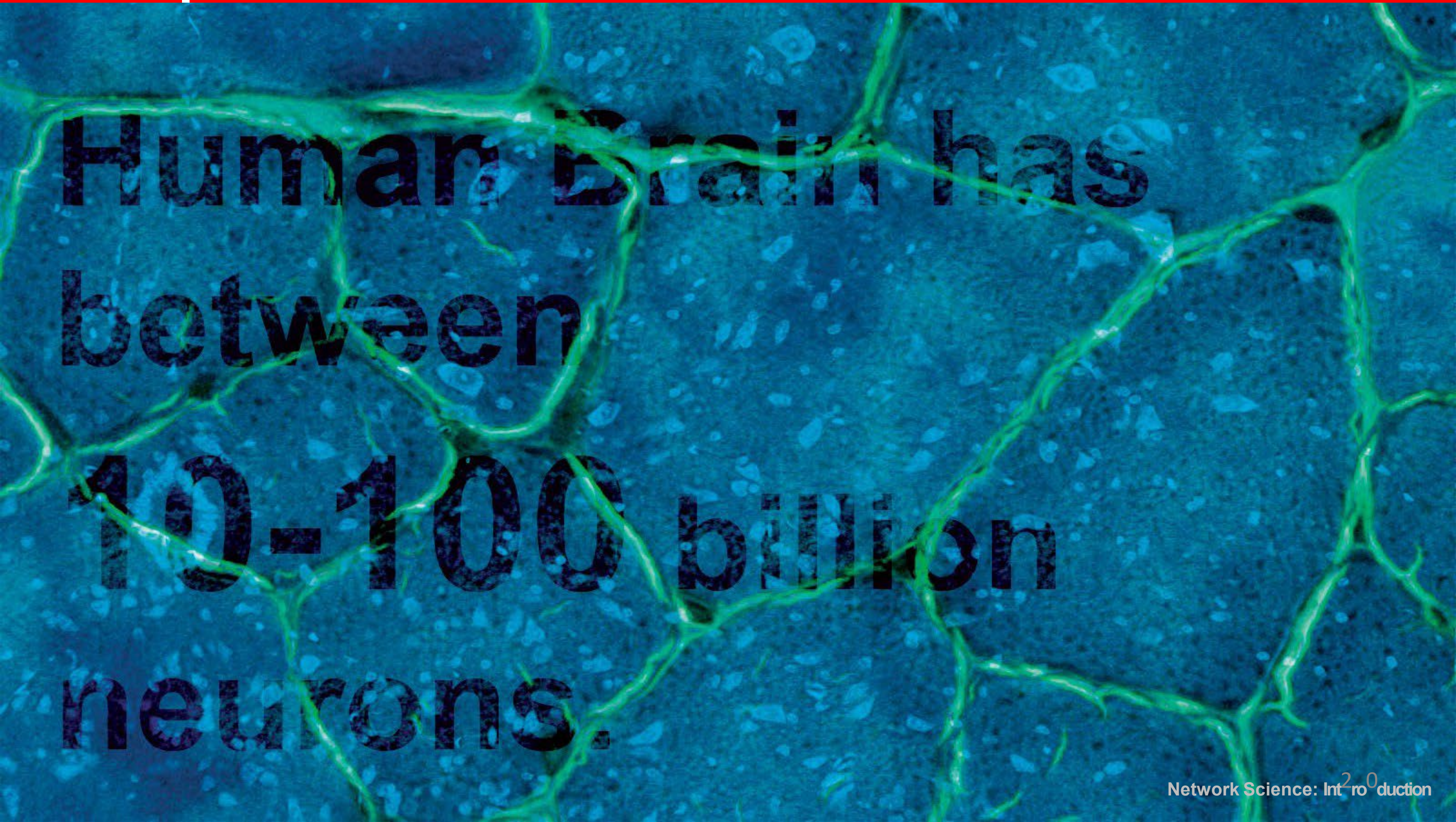
Factoid:

The population of 9-10 billions people has been predicted by the United States Census Bureau to be in 2050.

http://en.wikipedia.org/wiki/World_population

BRAIN **Factoid:**

Human Brain has between 10-100 billion neurons.



ECONOMY | Factoid:

The world economy will produce goods and services worth $105 trillion in 2023.
(https://en.wikipedia.org/wiki/World_economy)

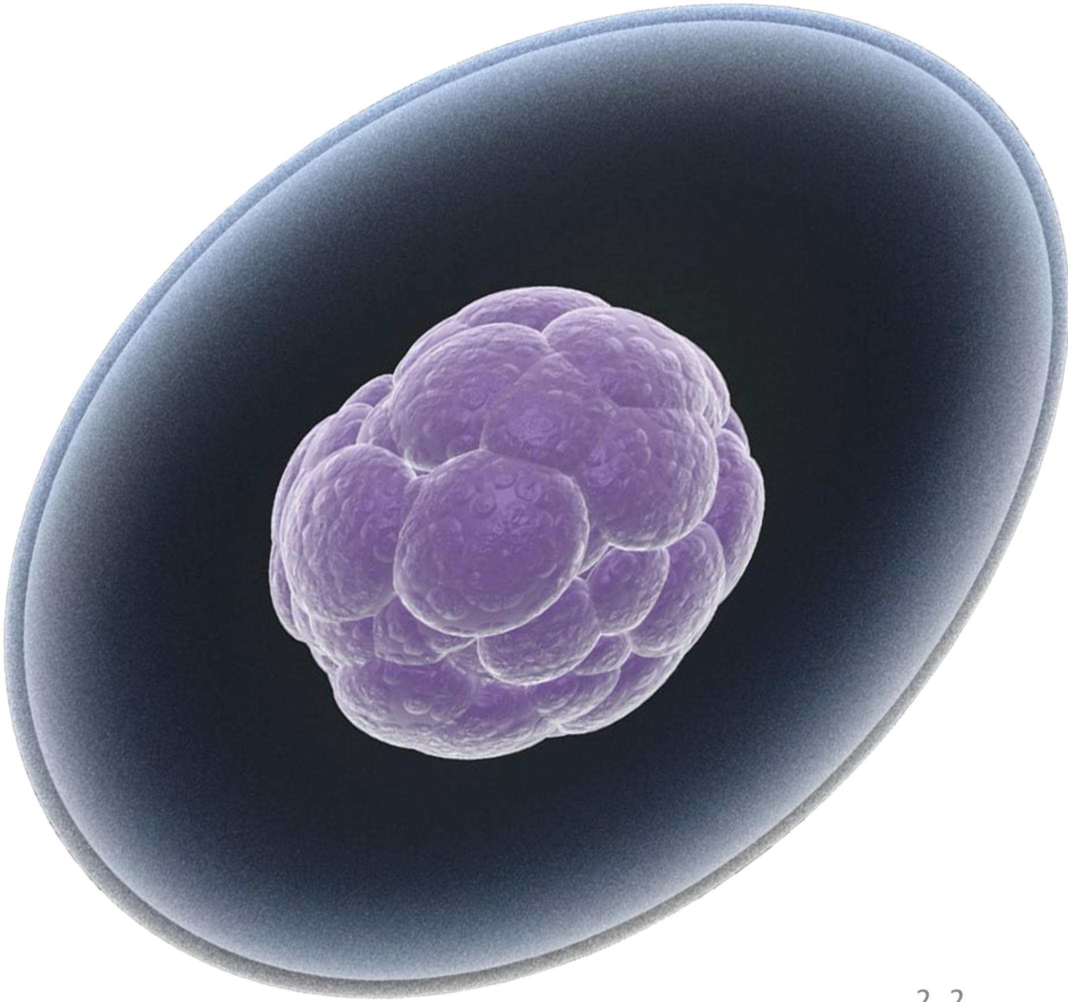
Factoid:

How Many Genes are in the Human Genome?

20,500

The latest number from 2007 is 20,500

The 20,500 number of protein-coding genes was presented in a 2007 PNAS paper. Scientists arrived at this number by excluding the (now thought to be functionally meaningless, random occurrences)
M. Clamp et al., 2007. "Distinguishing Protein-Coding and Noncoding Genes in the Human Genome," *PNAS* **104**(49), 19428-19433.]



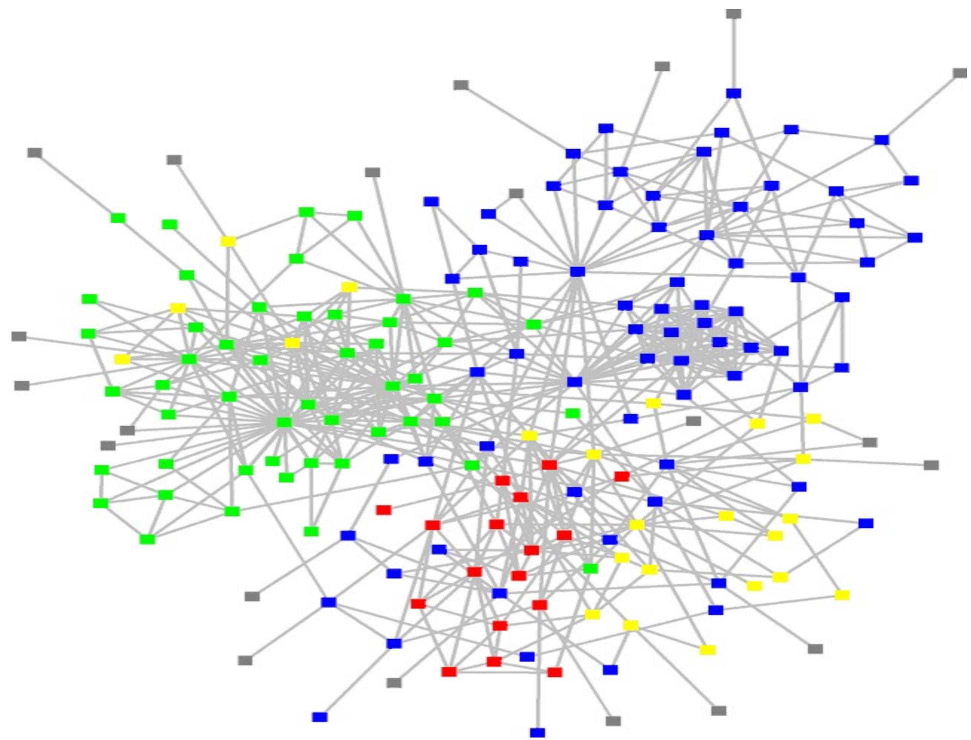
Behind each complex system there is a **network**, that defines the interactions between the components.

SOCIETY | Factoid:

The “Social Graph” behind Facebook

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

STRUCTURE OF AN ORGANIZATION



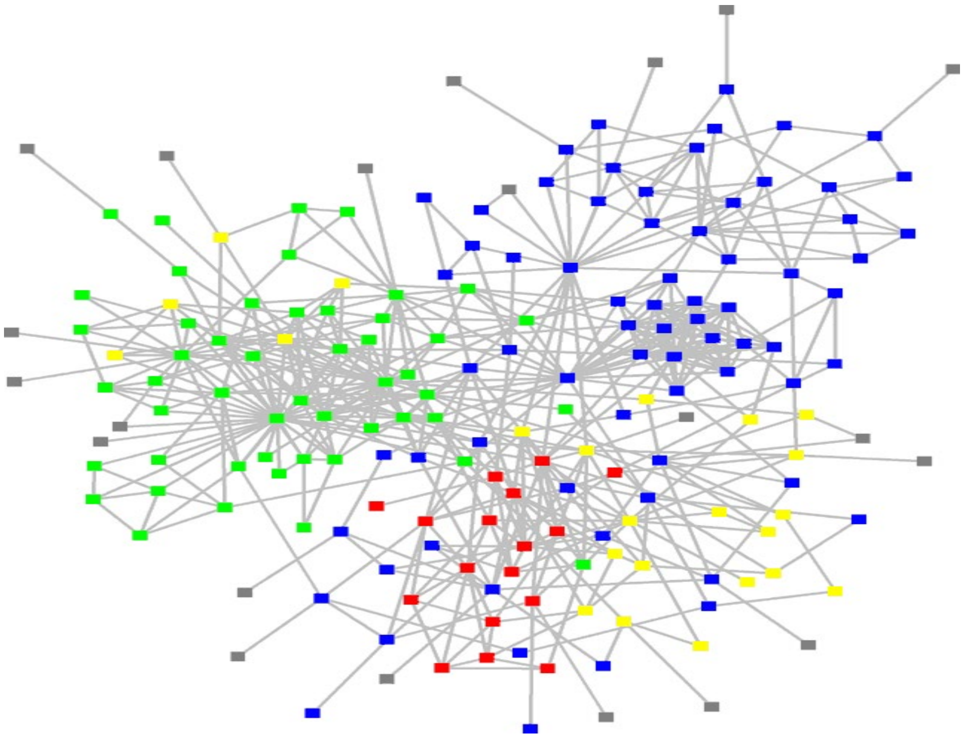
www.orgnet.com

: departments

: consultants

: external experts

STRUCTURE OF AN ORGANIZATION



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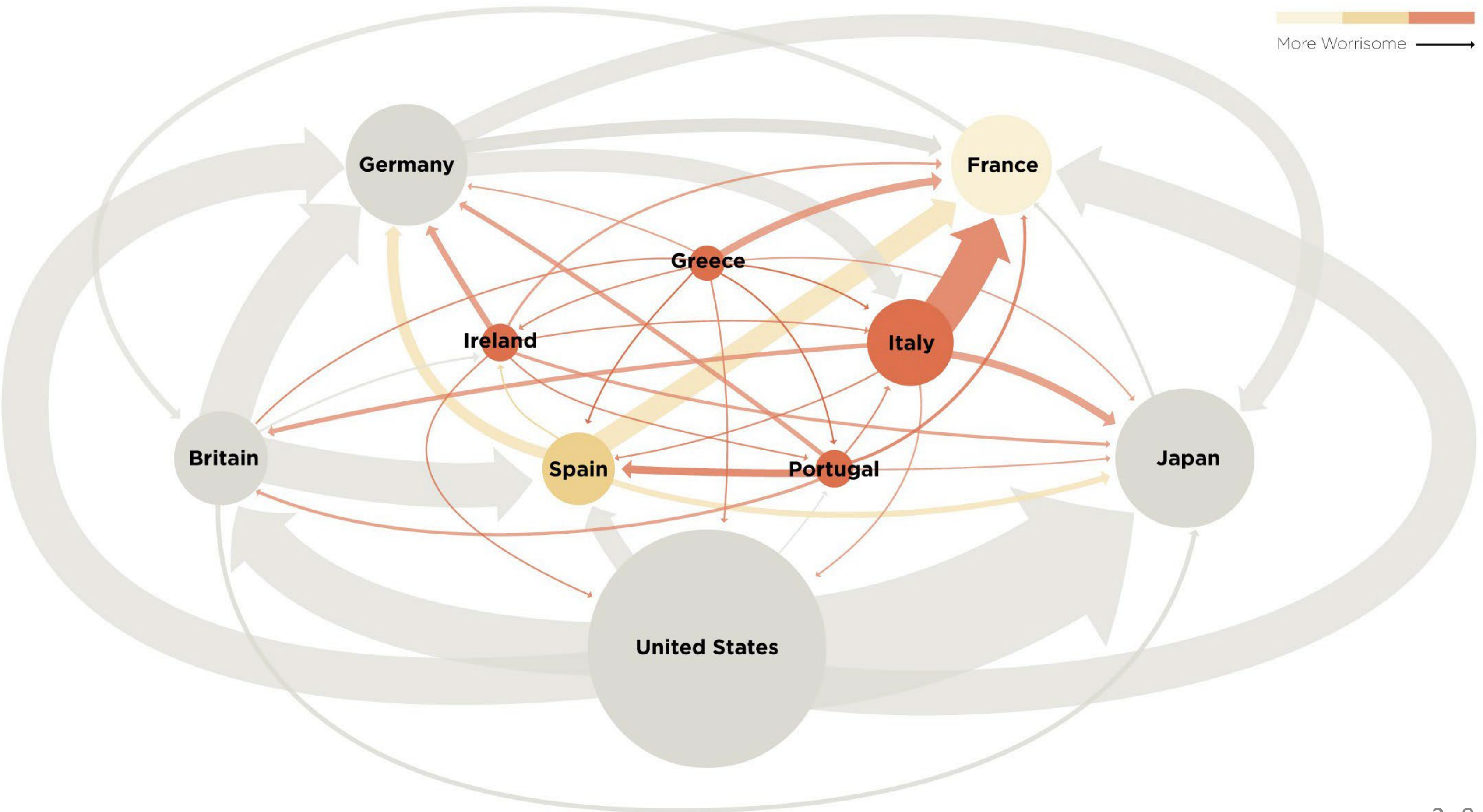
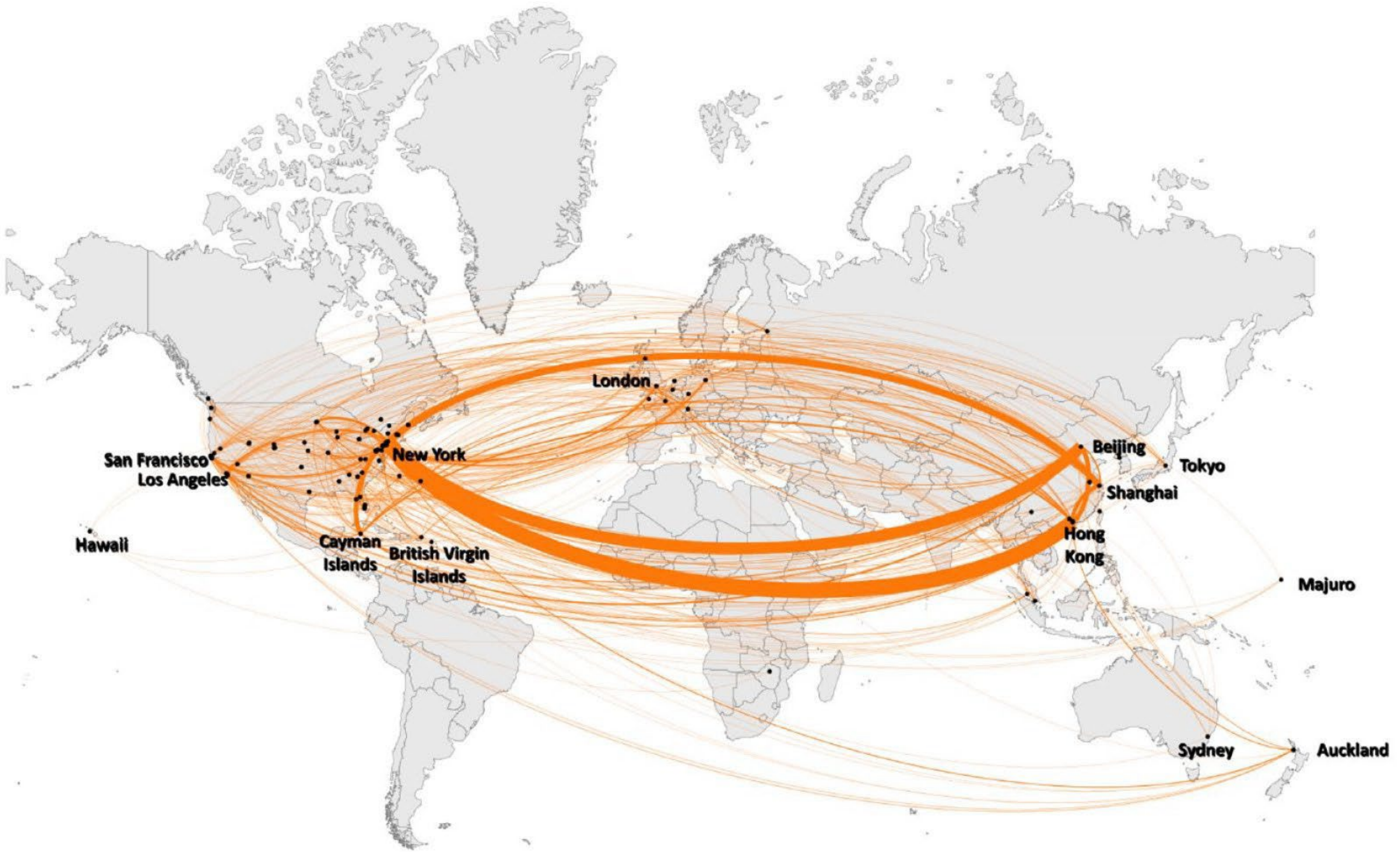
The subtle financial networks

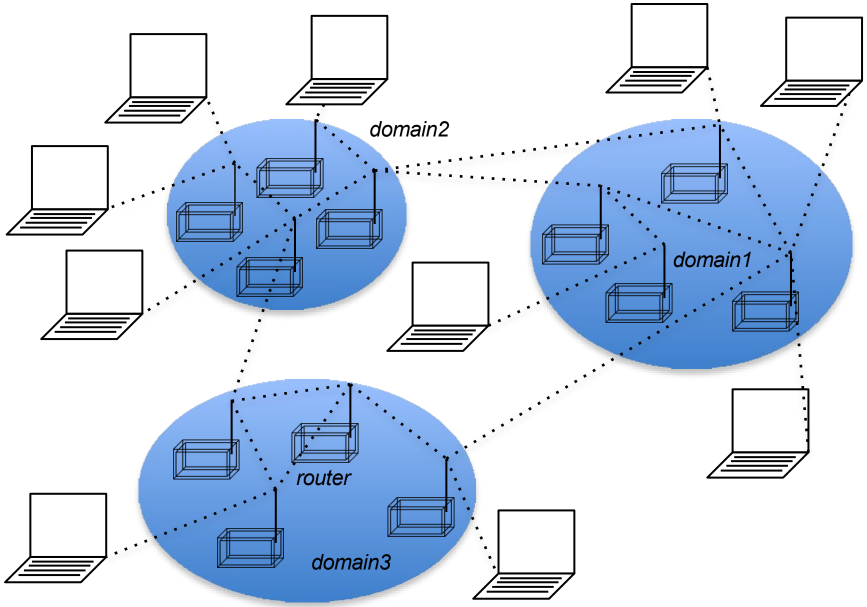
The not so subtle financial networks: 2011

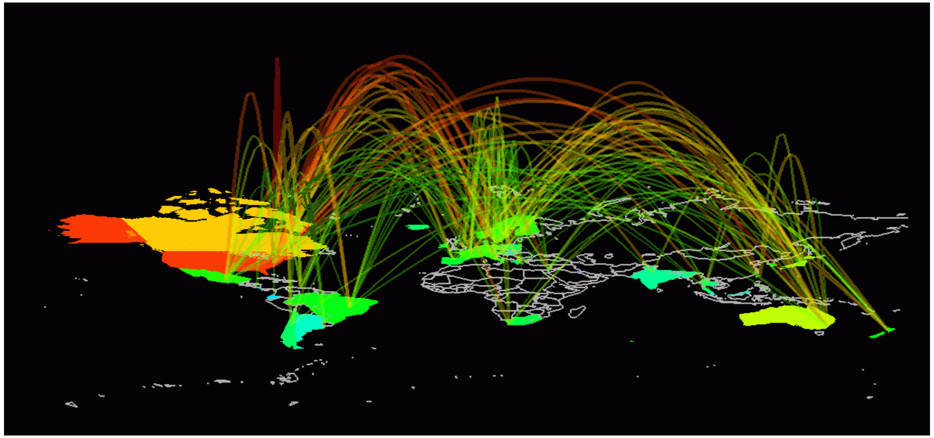


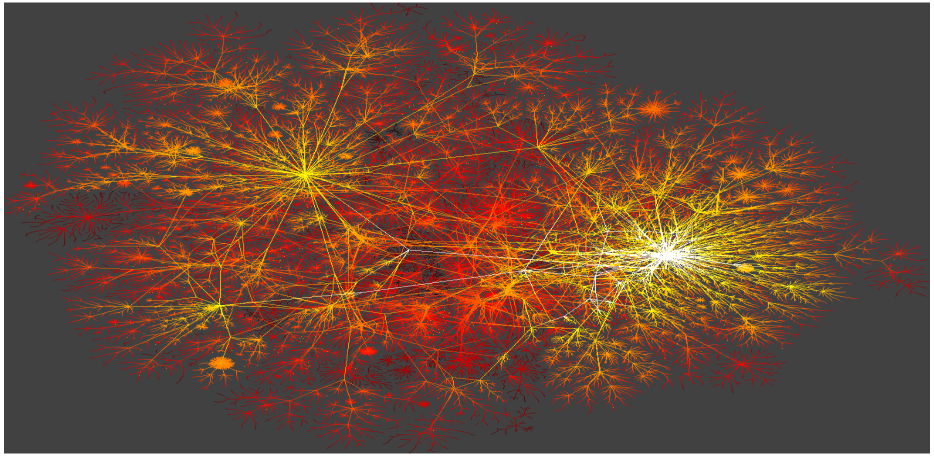
Chinese companies with foreign listings: 2022



INTERNET



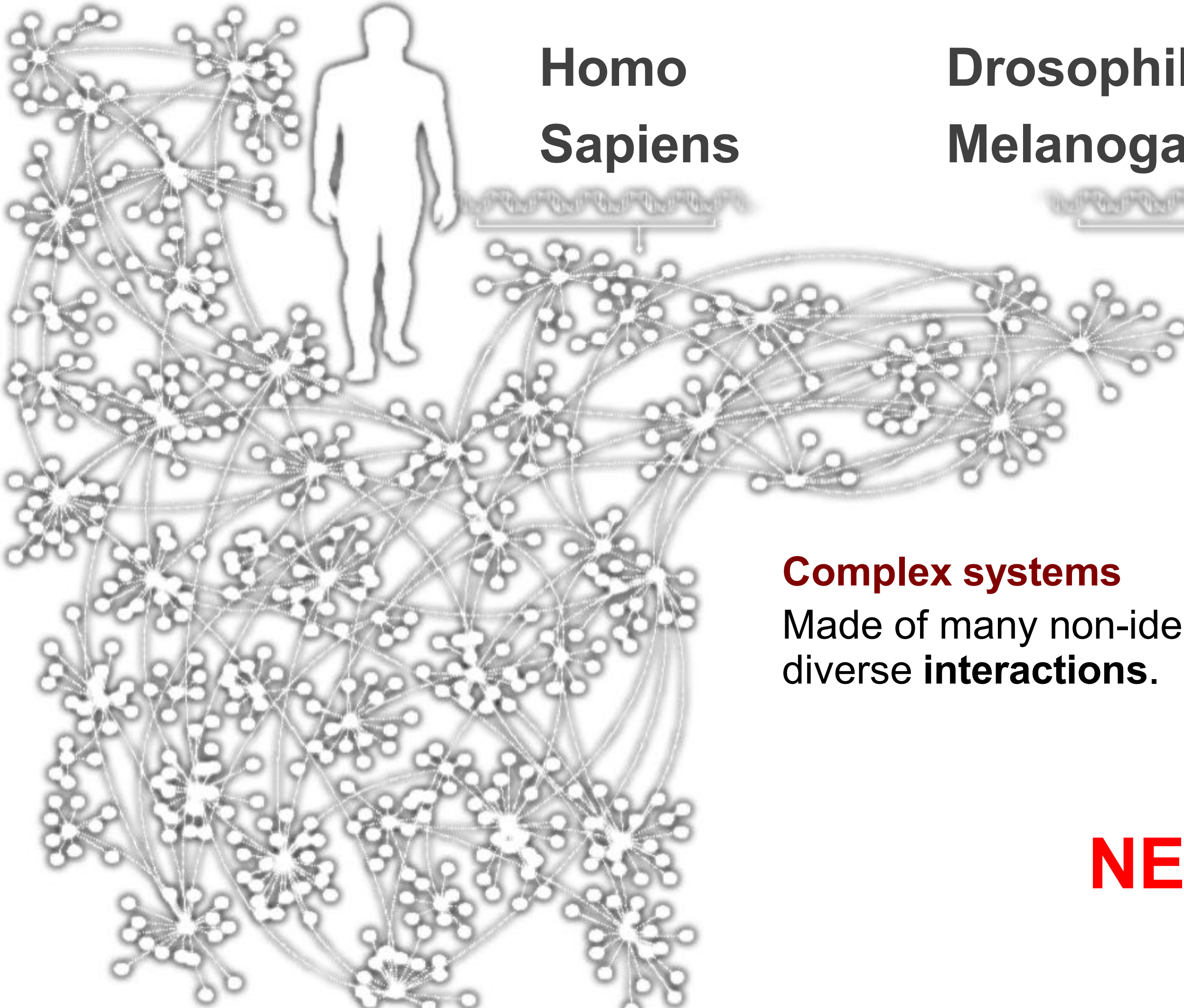




Factoid:

Human Brain has between 10-100 billion neurons.

HUMANS GENES



Complex systems

Made of many non-identical **elements** connected by diverse **interactions**.

NETWORK

THE ROLE OF NETWORKS

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.

TWO FORCES HELPED THE EMERGENCE OF NETWORK SCIENCE

The emergence of network maps:

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

The 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.

Data Availability:

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

Universality:

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

The (urgent) need to understand complexity:

Despite the challenges complex systems offer us, we cannot afford to not address their behavior, a view increasingly shared both by scientists and policy makers. Networks are not only essential for this journey, but during the past decade some of the most important advances towards understanding complexity were provided in context of network theory.

THE HISTORY OF NETWORK ANALYSIS

Graph theory: 1735, Euler

Social Network Research: 1930s, Moreno

Communication networks/internet: 1960s

Ecological Networks: May, 1979.

THE TOOLS OF MODERN NETWORK THEORY

> Graph theory

> Social network theory

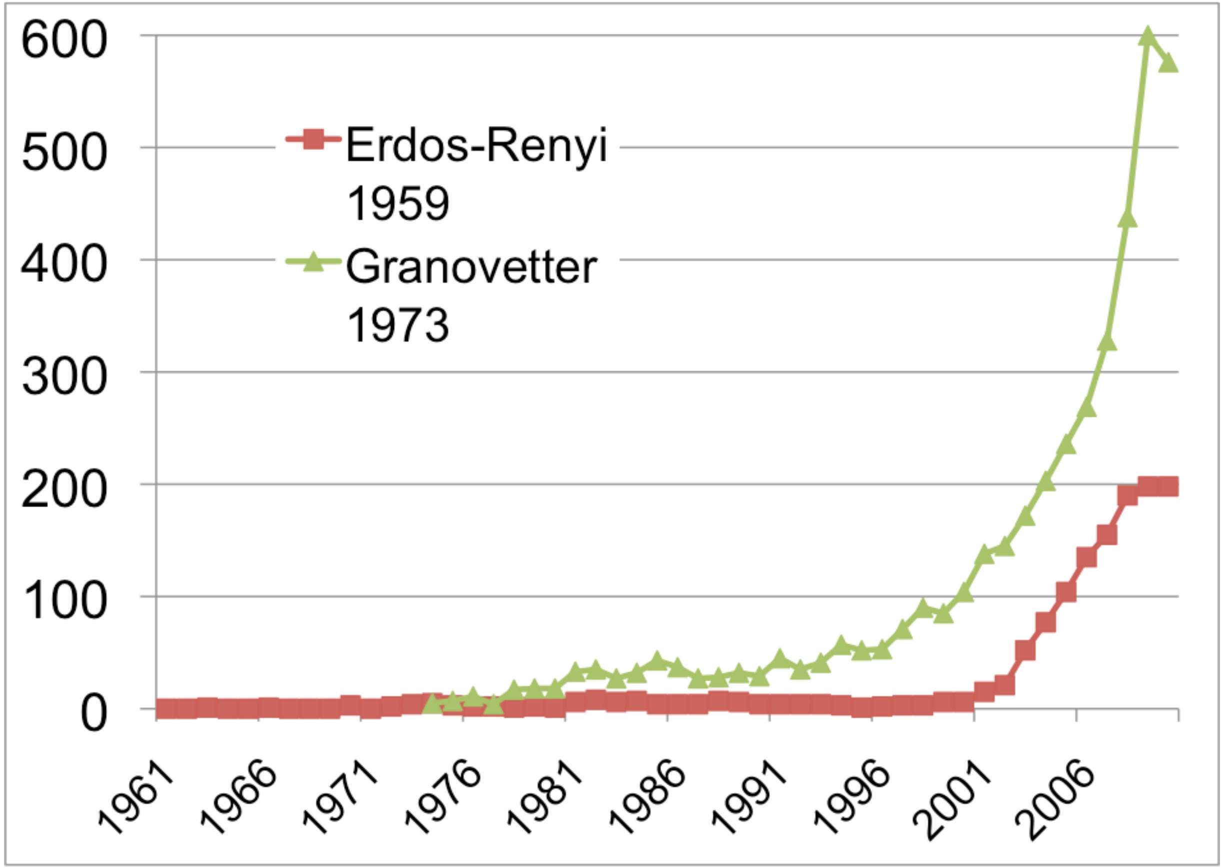
> Statistical physics

> Computer science

> Biology

> Statistics

THE HISTORY OF NETWORK ANALYSIS



THE CHARACTERISTICS OF NETWORK SCIENCE

THE CHARACTERISTICS OF NETWORK SCIENCE

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational

THE CHARACTERISTICS OF NETWORK SCIENCE

Interdisciplinary

Empirical, data driven

Quantitative and Mathematical

Computational

THE CHARACTERISTICS OF NETWORK SCIENCE

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational

THE CHARACTERISTICS OF NETWORK SCIENCE

Interdisciplinary

Empirical

Quantitative and Mathematical

Computational

THE IMPACT OF NETWORK SCIENCE

Quantum Mechanics: 1900

- **electron microscope** 1931
- **transistor** 1947
- **laser** 1957
- **magnetic resonance imaging** 1973
- **quantum computing** 2015

Much of modern **technology** operates at a scale where quantum effects are significant.

At least a 30 year gap between the science and technology.

ECONOMIC IMPACT

Google vs. Alphabet

Market Caps (August 2023):

$130 billion vs. 1,640 billion

Cisco Systems

networking gear Market

Market Cap (August 2023):

$225 billion

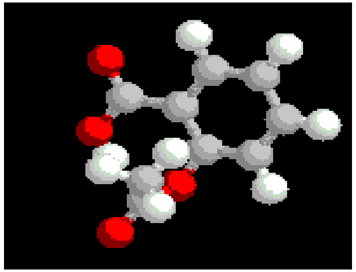
Facebook (Meta)

Market Cap (August 2023):

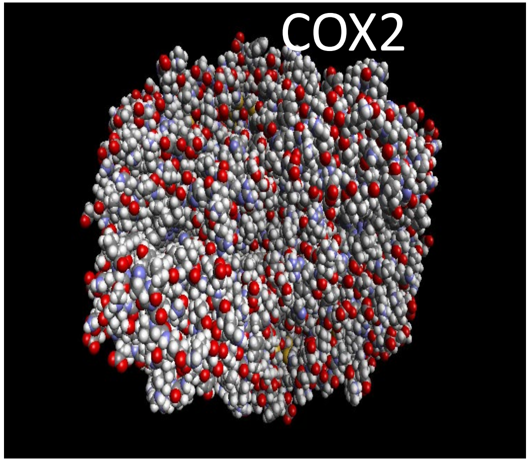
$738 billion

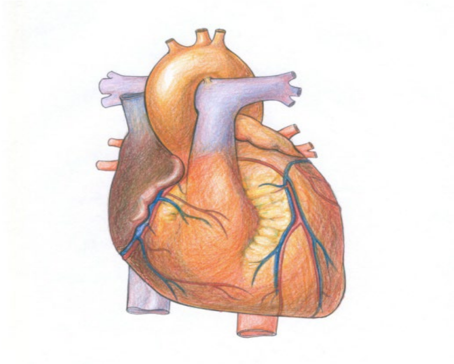
DRUG DESIGN, METABOLIC ENGINEERING:

Reduces
Inflammation
Fever
Pain



Causes
Bleeding
Ulcer





Reduces the risk of
Alzheimer's Disease

Reduces the risk of
breast cancer
ovarian cancers
colorectal cancer

Prevents
Heart attack
Stroke

DRUG DESIGN, METABOLIC ENGINEERING: