Network Science

Class 1: Introduction

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— Adapted from —
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(With Roberta Sinatra)

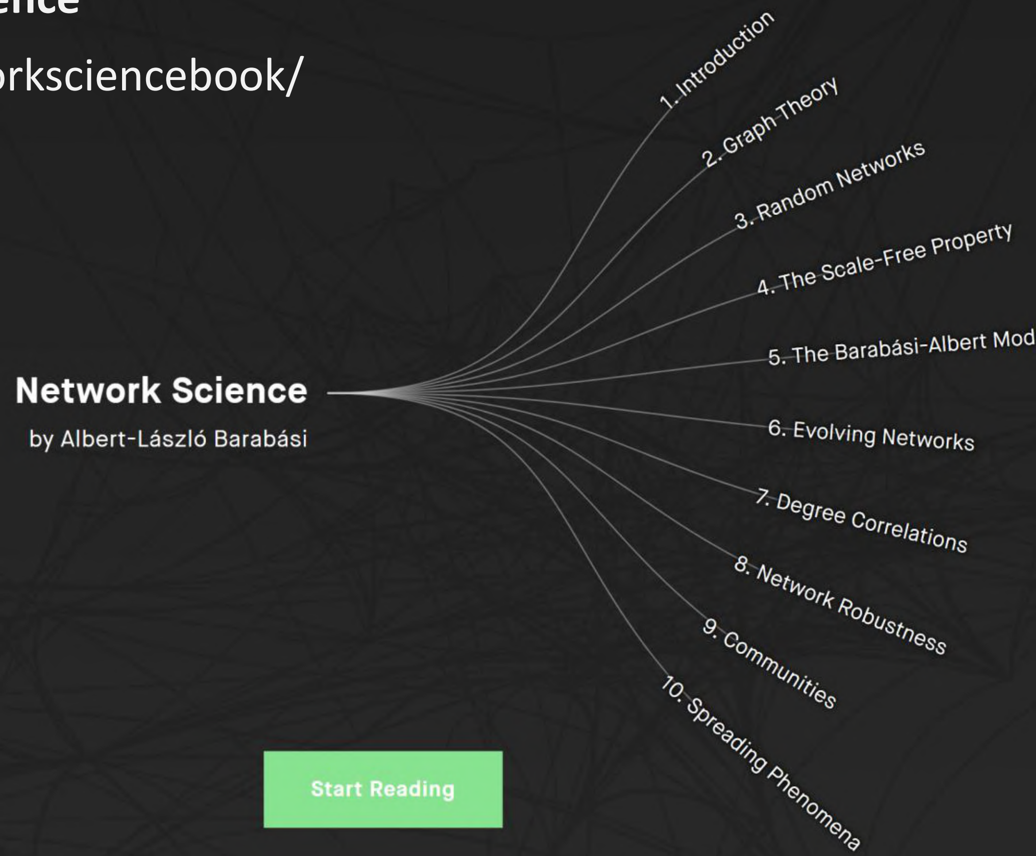
www.BarabasiLab.com

Albert-László Barabási

NETWORK SCIENCE

Online Book: Network Science

http://barabasi.com/networksciencebook/



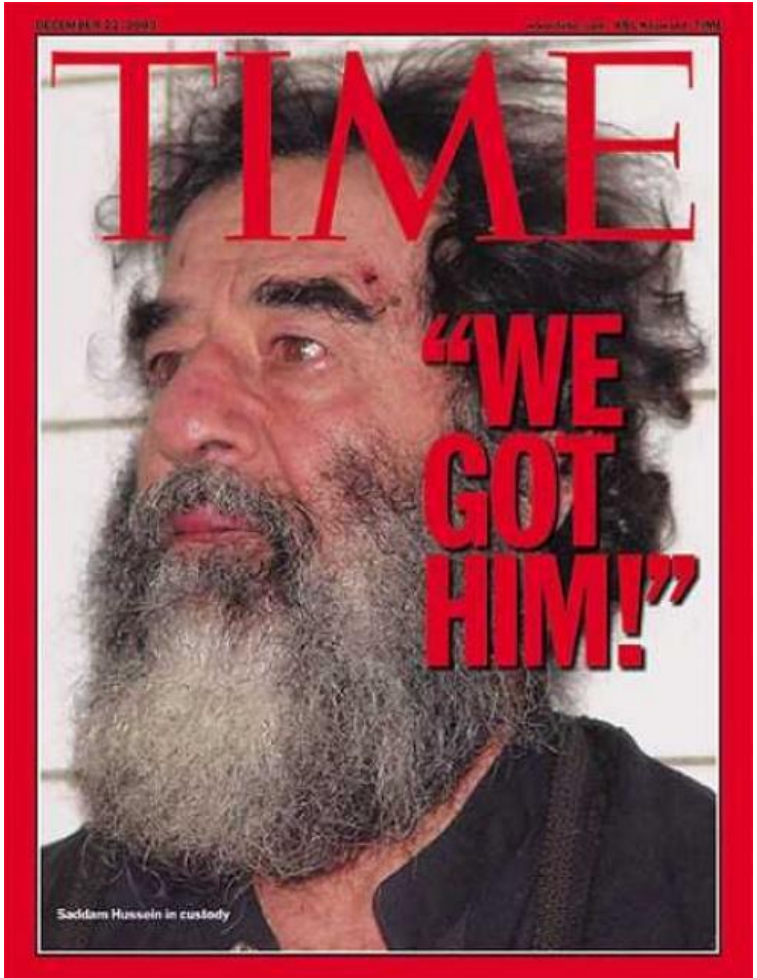
Complex Systems

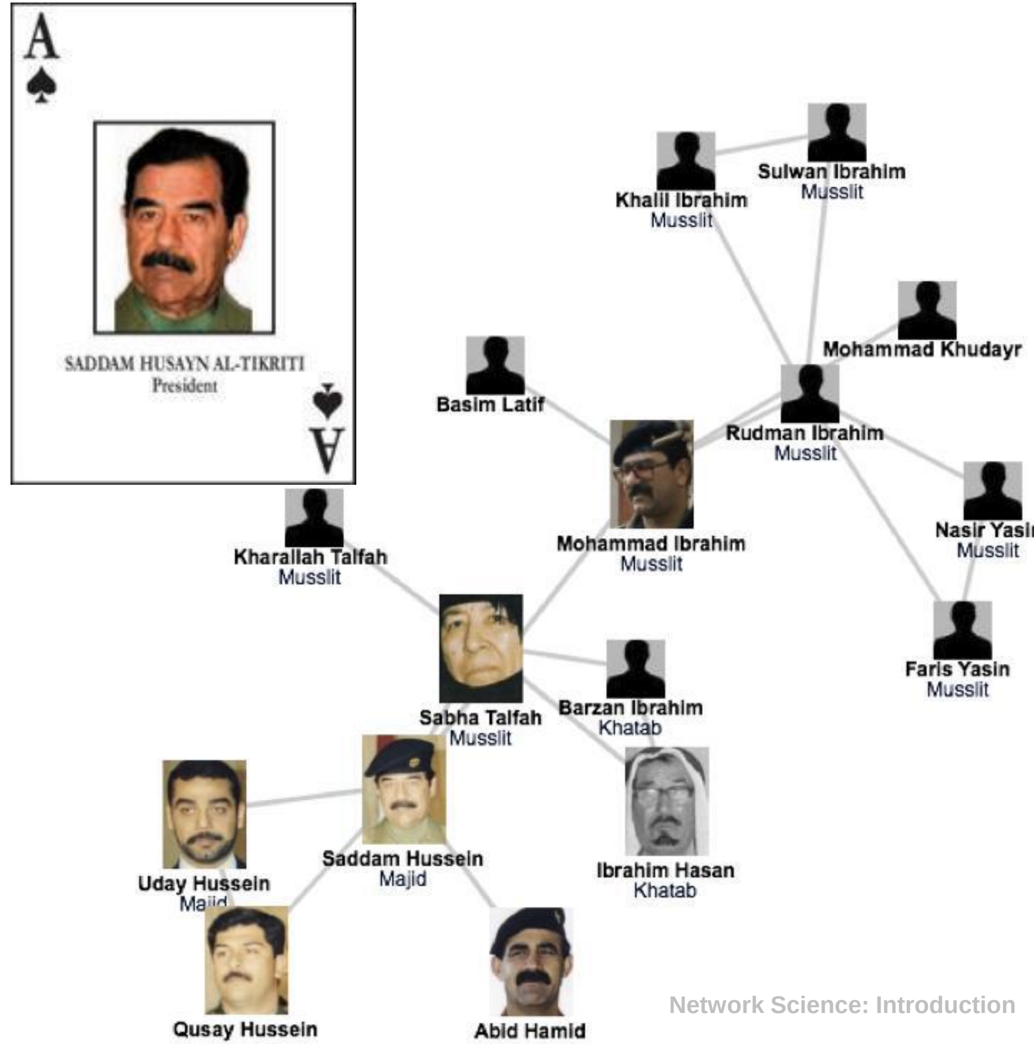
A system comprising of large number of sophisticated functional elements, intricately connected with each other to perform specific tasks, which otherwise can not be executed by subsets of the system.

SUM OF PARTS
– IS NOT THE SAME AS –
THE WHOLE

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.

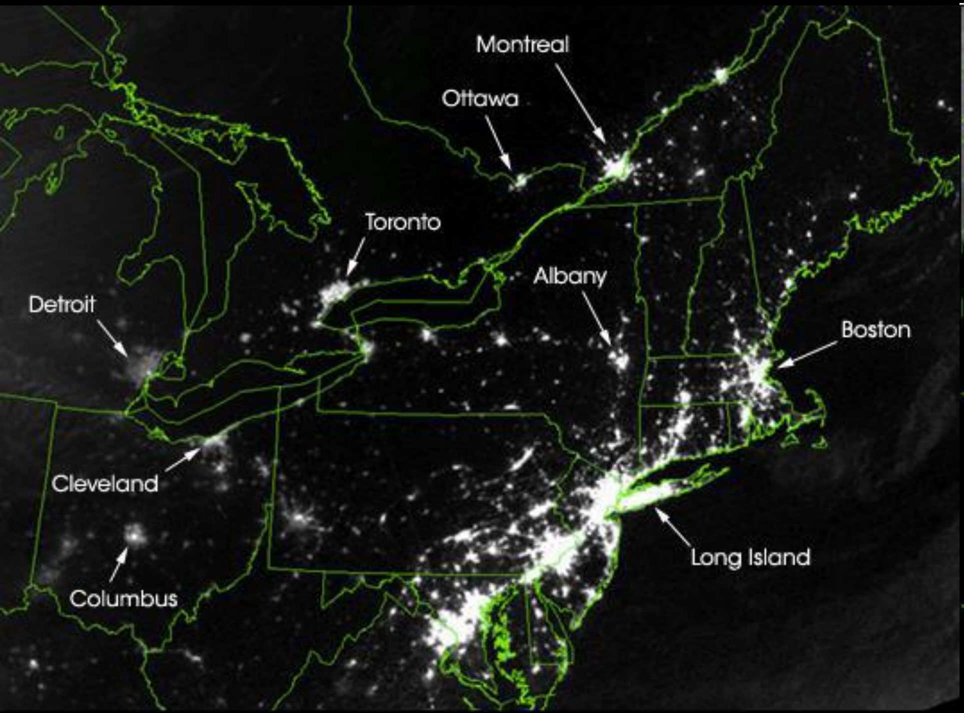
→ underlies the **need to obtain accurate maps** of the networks we aim to study; and the often heroic difficulties we encounter during the mapping process.

→ 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.

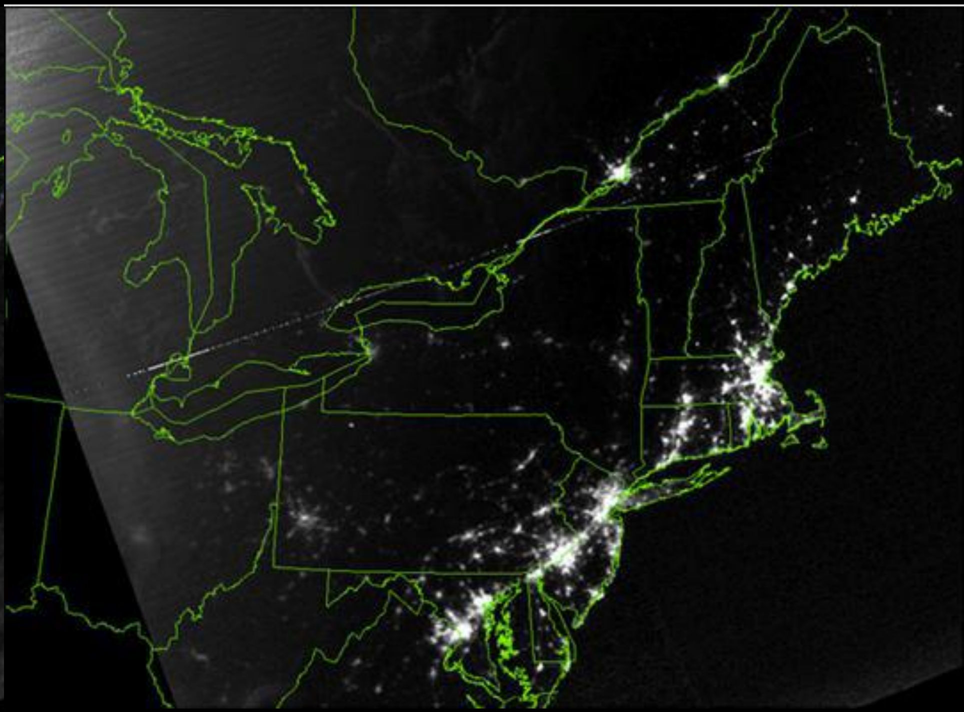
→ shows that the **choice of network** we focus on makes a huge difference: the hierarchical tree, that captured the official organization of the Iraqi government, was of no use when it came to Saddam Hussein's whereabouts.

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

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

An important theme of this class:

→ we must understand **how network structure affects 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 follow reproducible laws**, that can be quantified and even predicted using the tools of network science.

NETWORKS AT THE HEART OF COMPLEX SYSTEMS

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.

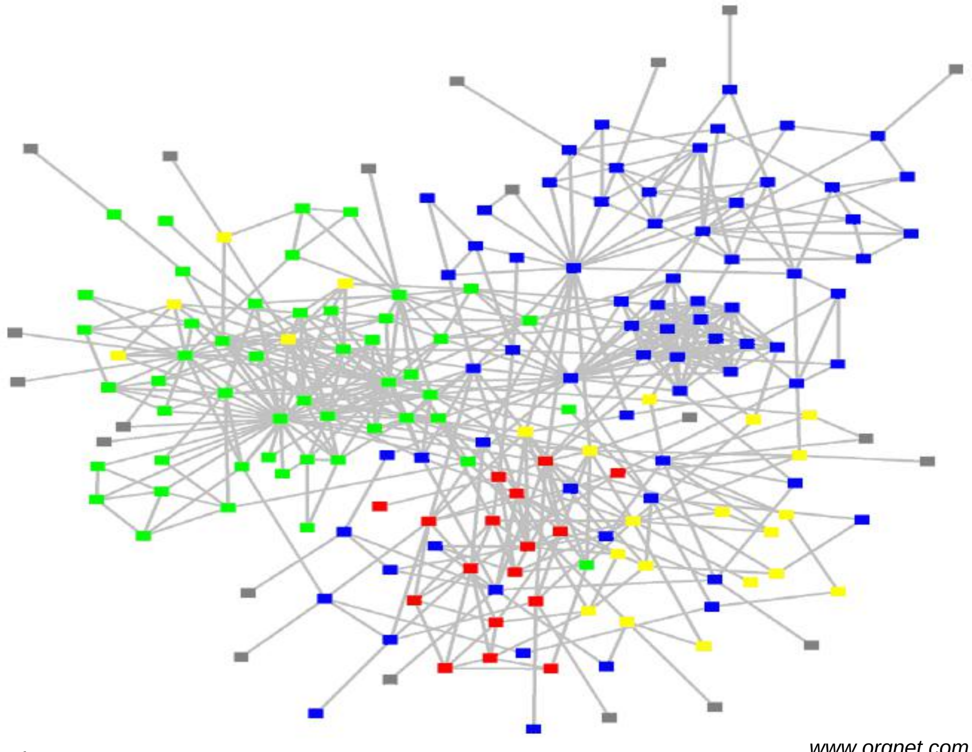
SOCIETY

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



: departments

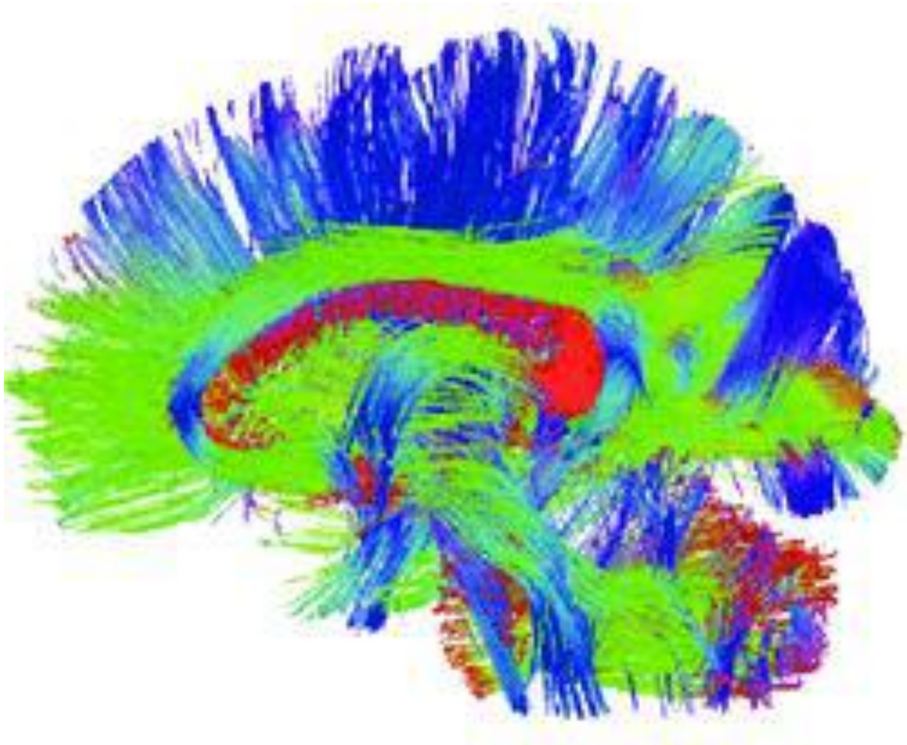
: consultants

: external experts

Factoid:

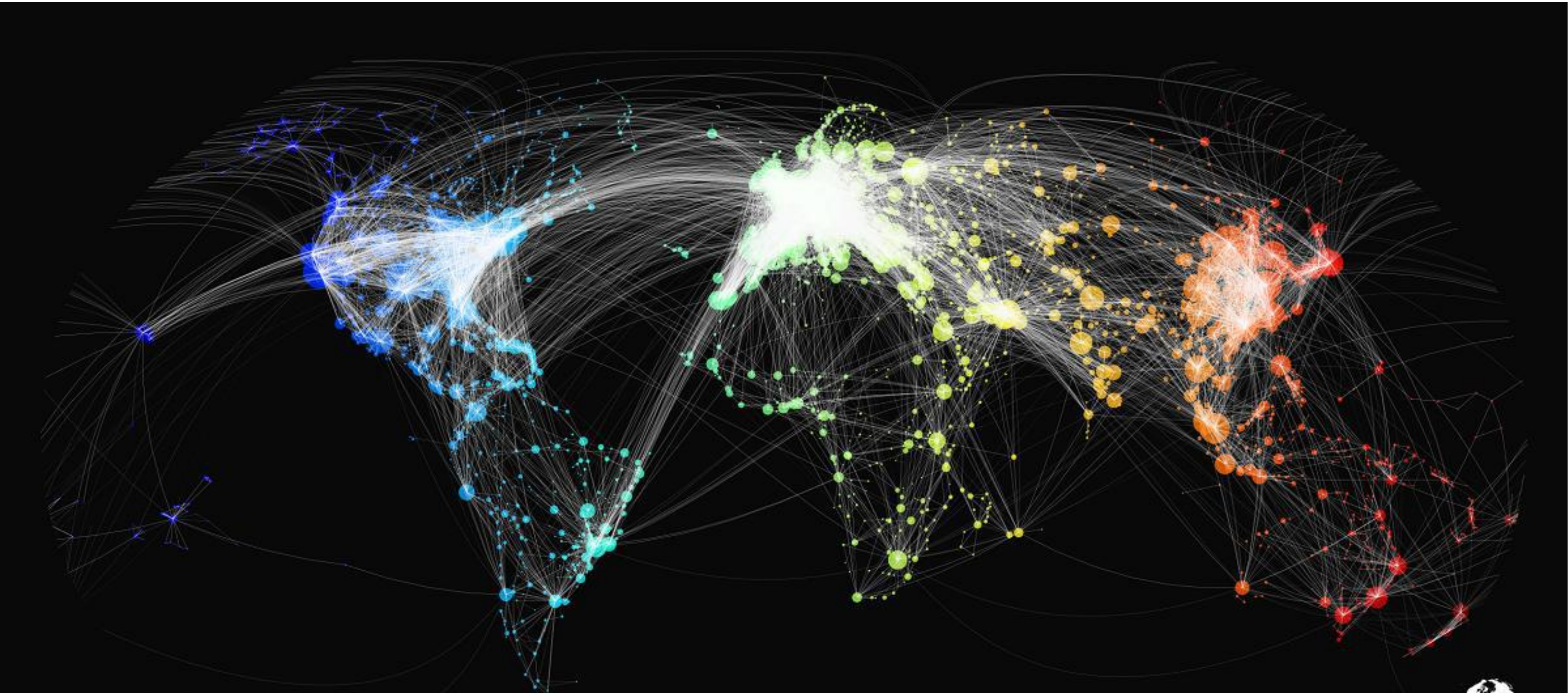
Human Brain has between 10-100 billion neurons.

BRAIN



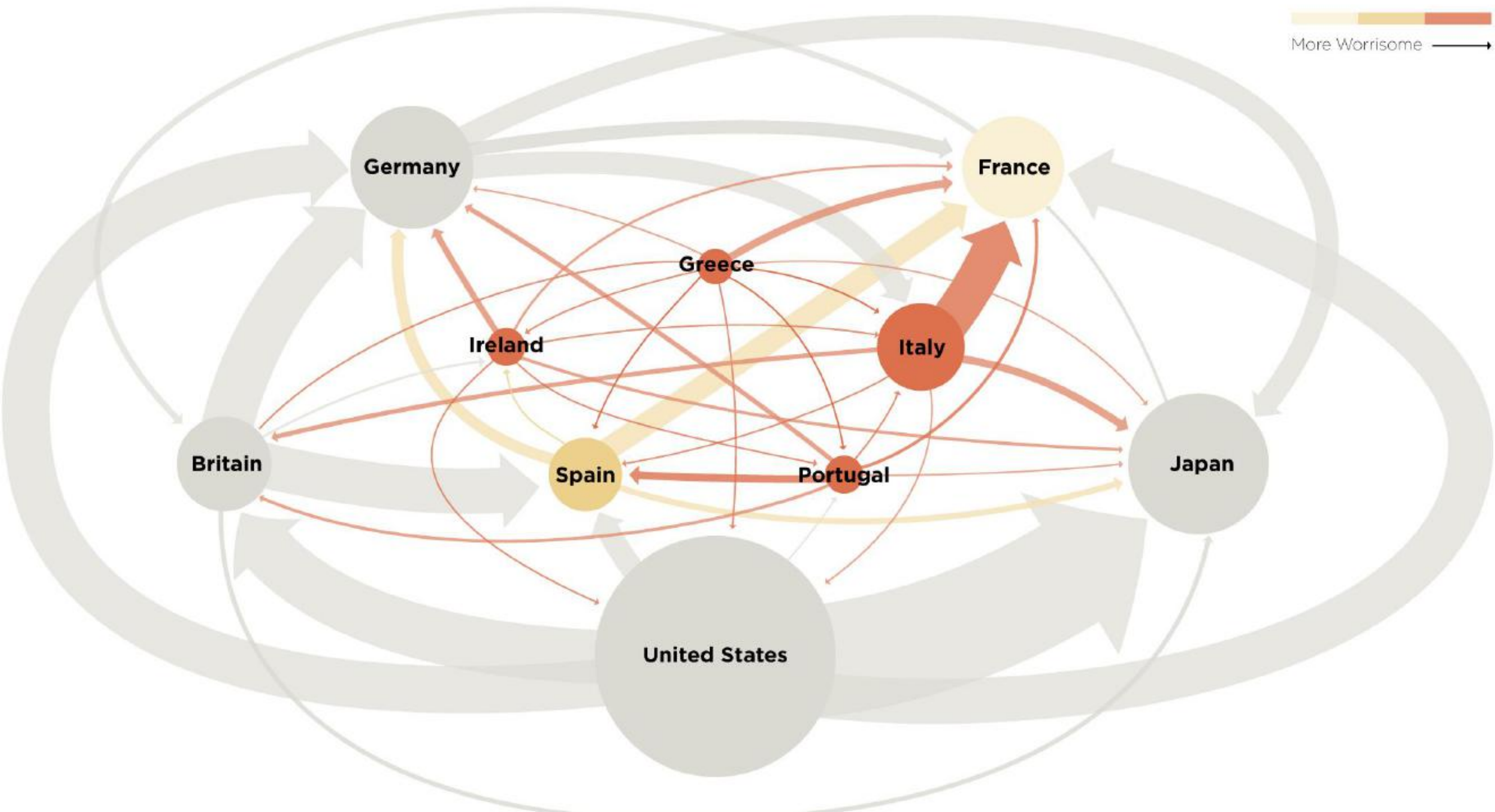
The subtle financial networks

The transportation networks



Airways. @PythonMaps
This map shows the world's flight paths and airports. It maps 10,000 airports and 67,663 routes linking those airports.
Data source - https://openflights.org/data.html

The not so subtle financial networks: 2011



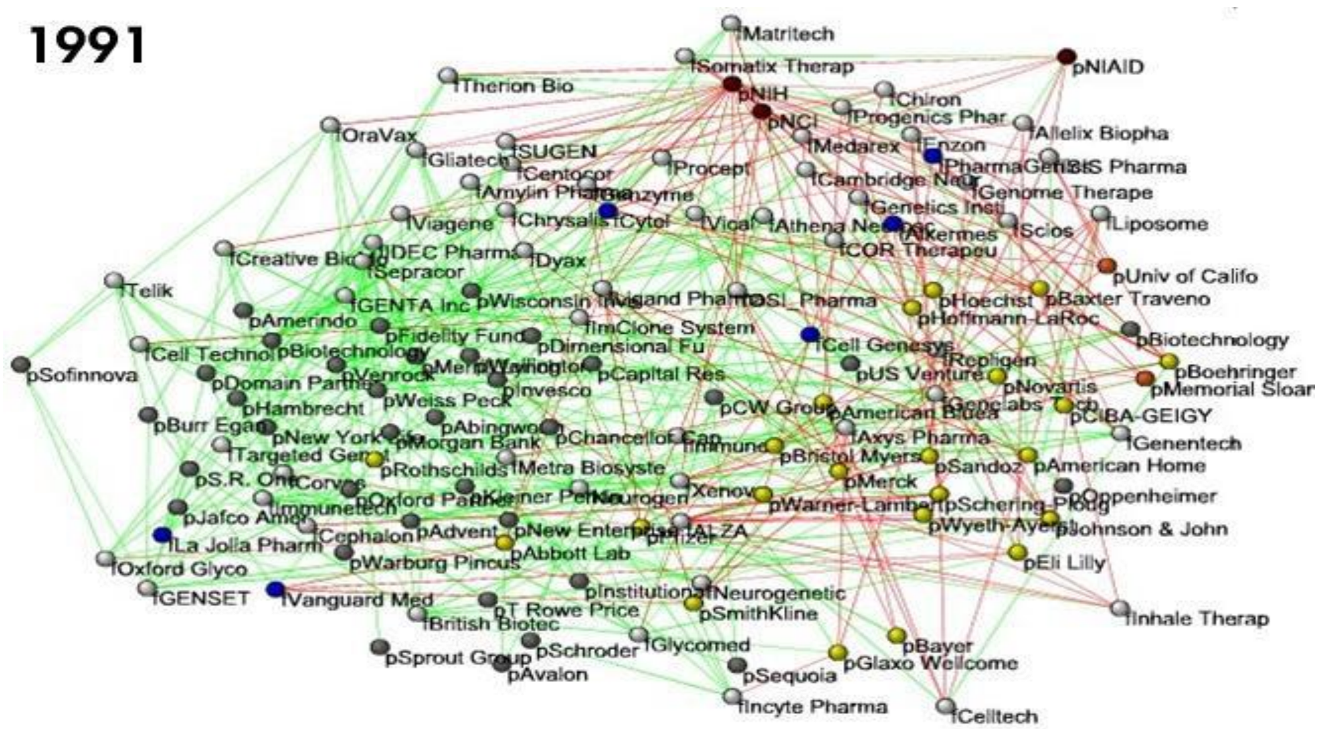
BUSINESS TIES IN US BIOTECH-INDUSTRY

Nodes:

- Companies
- Investment
- Pharma
- Research Labs
- Public
- Biotechnology

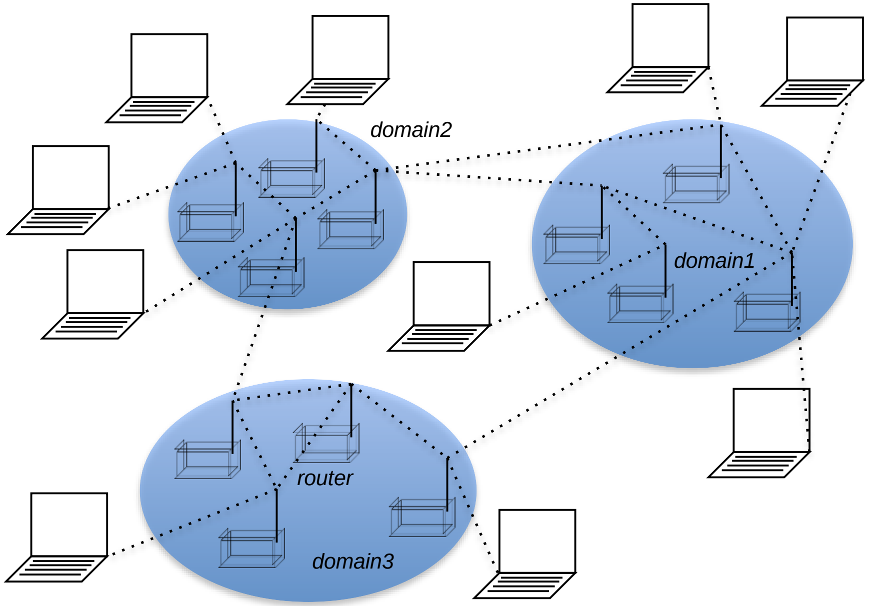
Links:

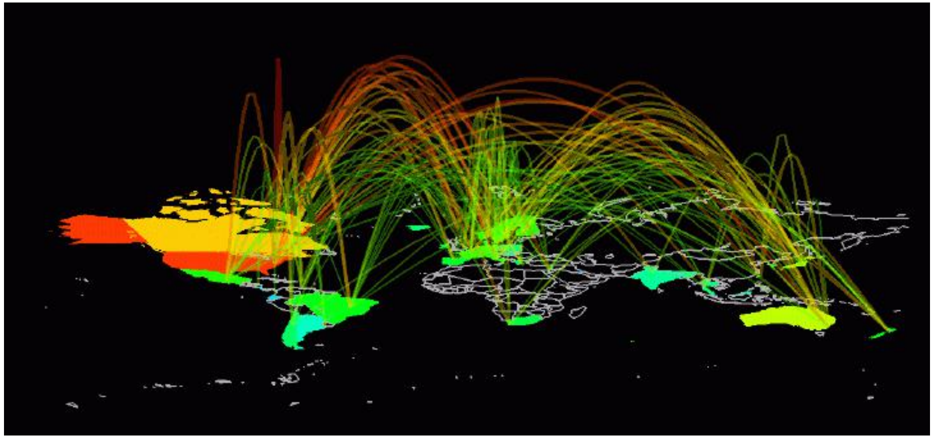
- Collaborations
- Financial
- R&D

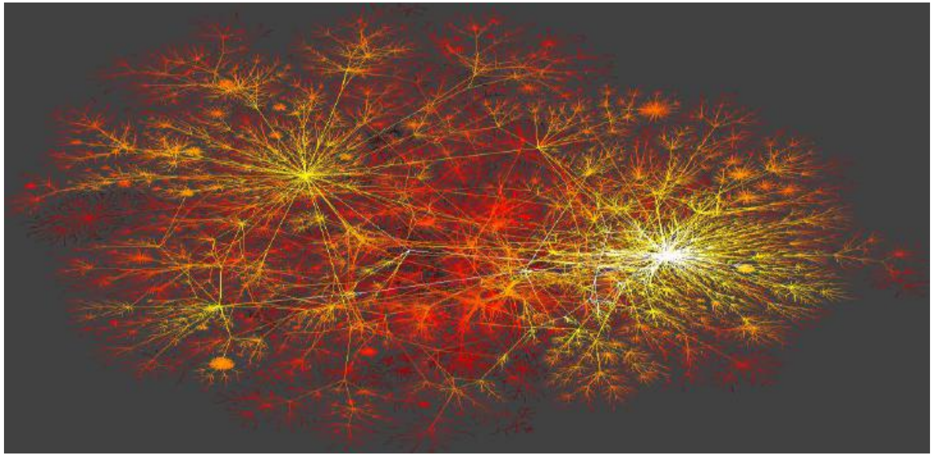


http://ecclectic.ss.uci.edu/~drwhite/Movie

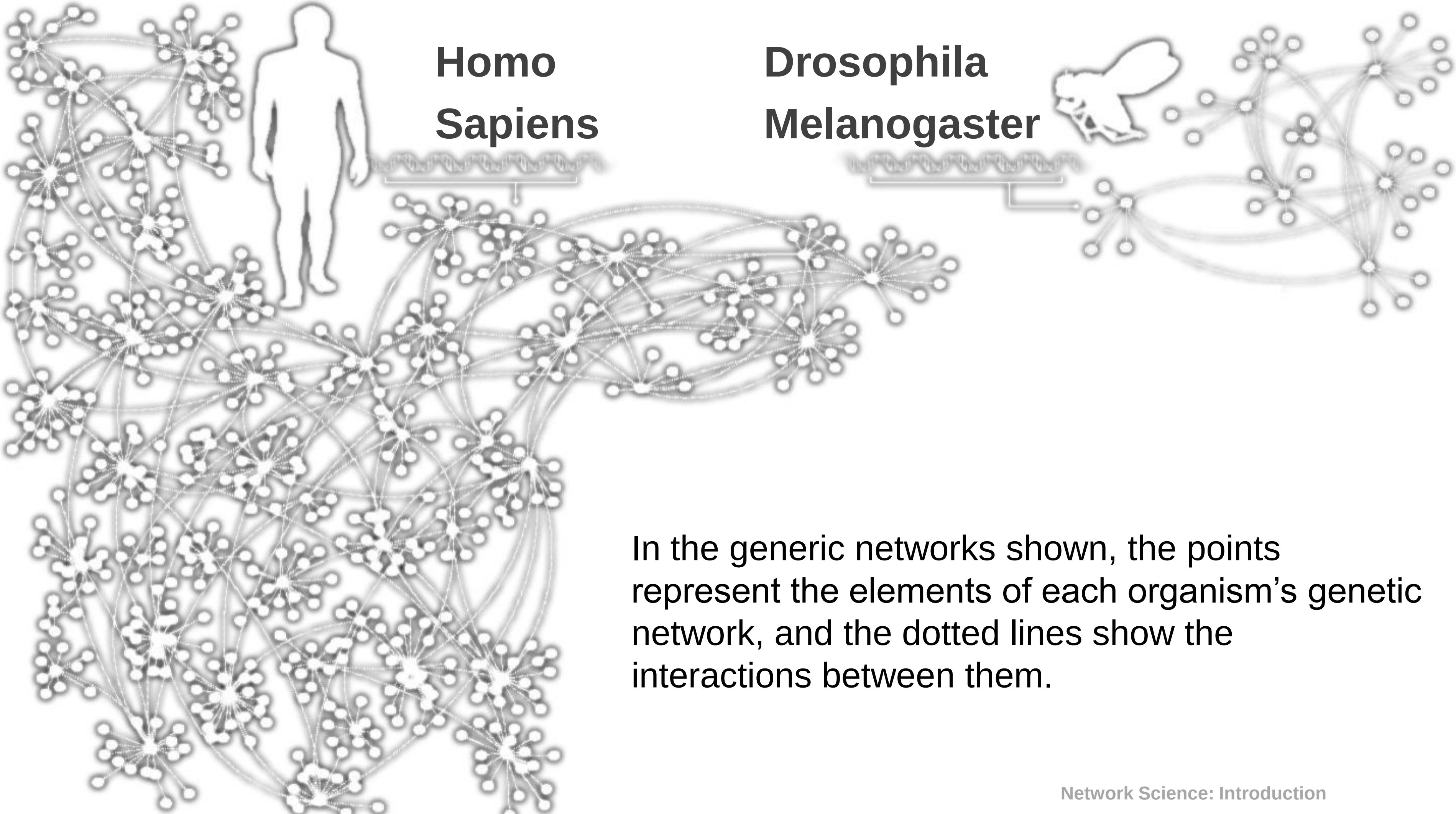
INTERNET





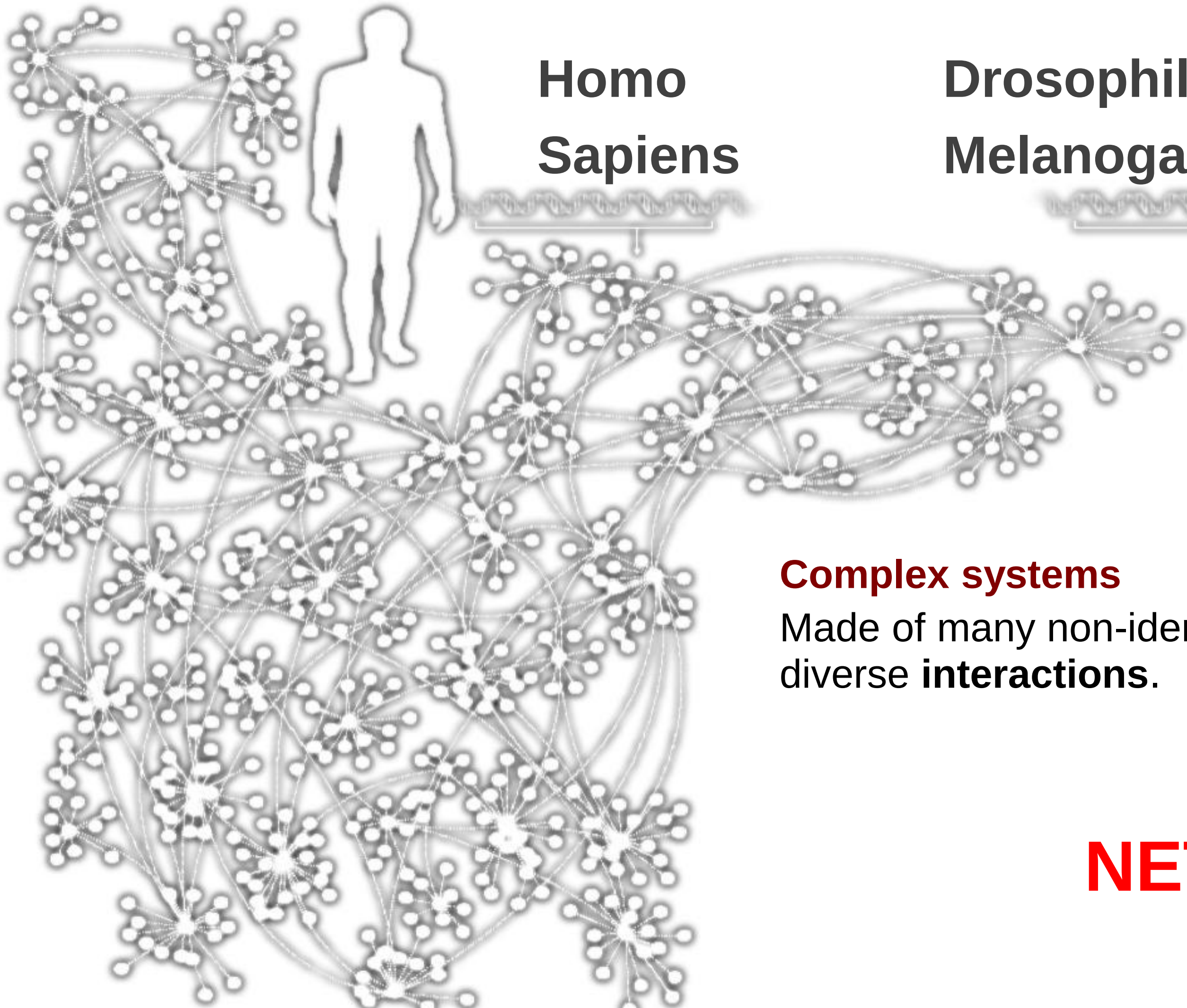


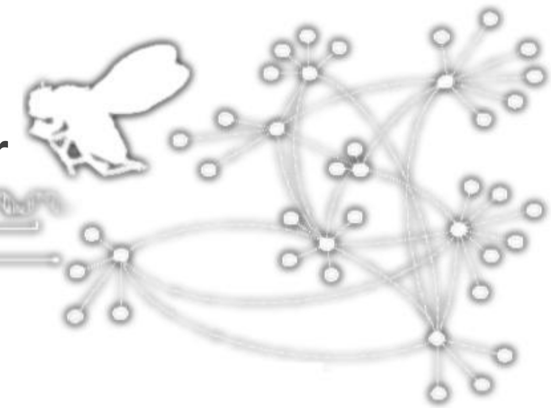
HUMANS GENES



In the generic networks shown, the points represent the elements of each organism's genetic network, and the dotted lines show the interactions between them.

HUMANS GENES



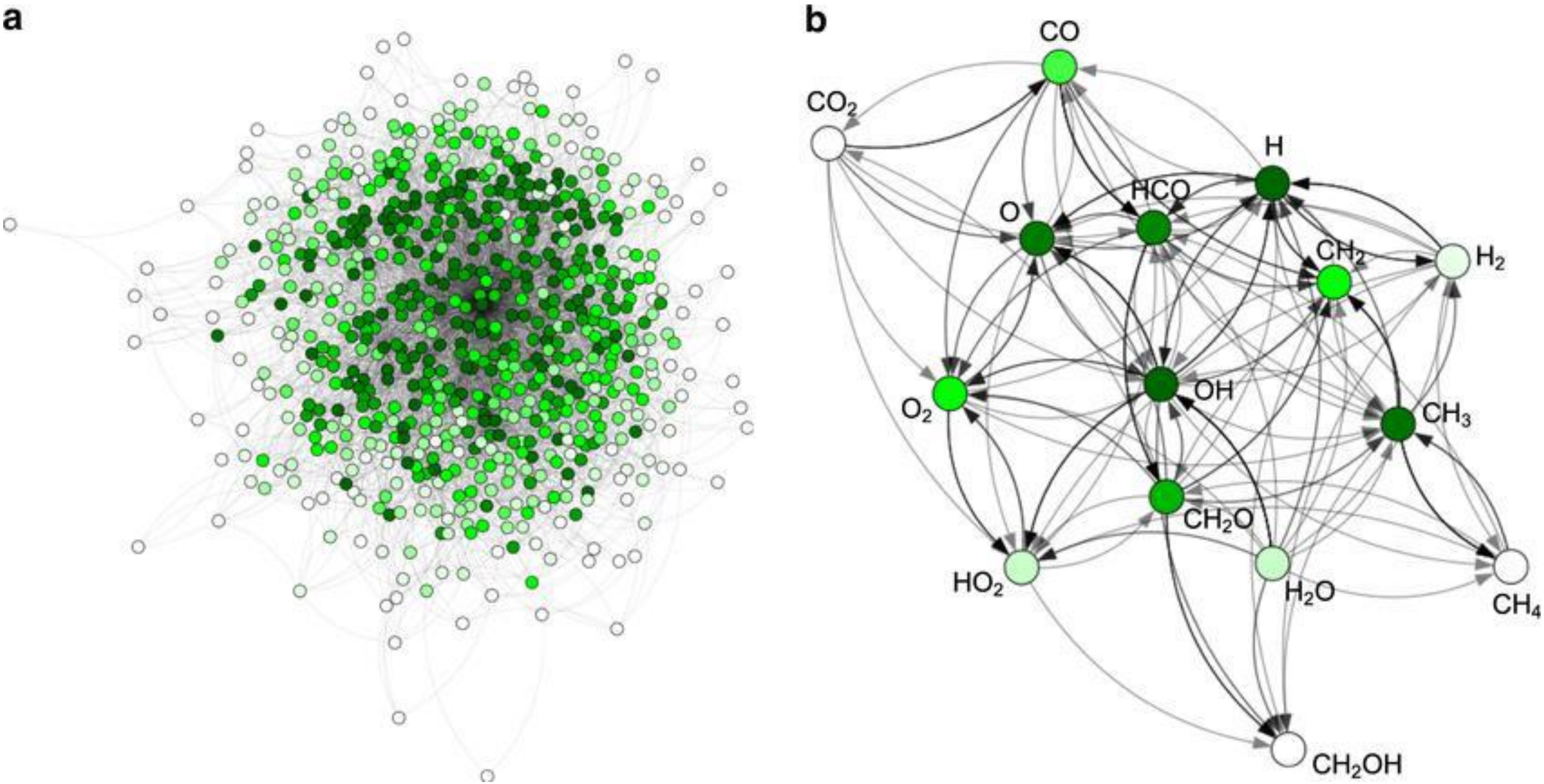


Complex systems

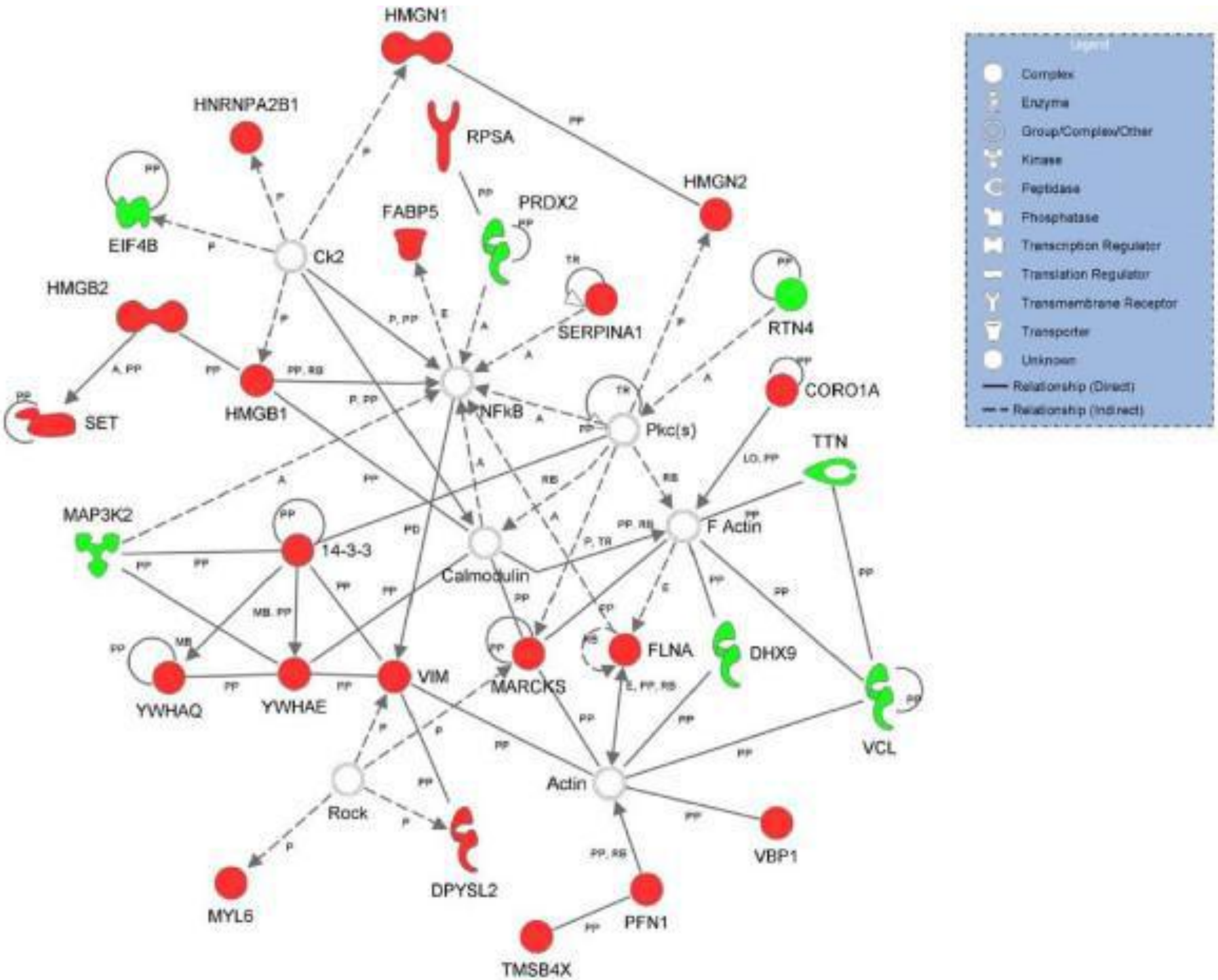
Made of many non-identical **elements** connected by diverse **interactions**.

NETWORK

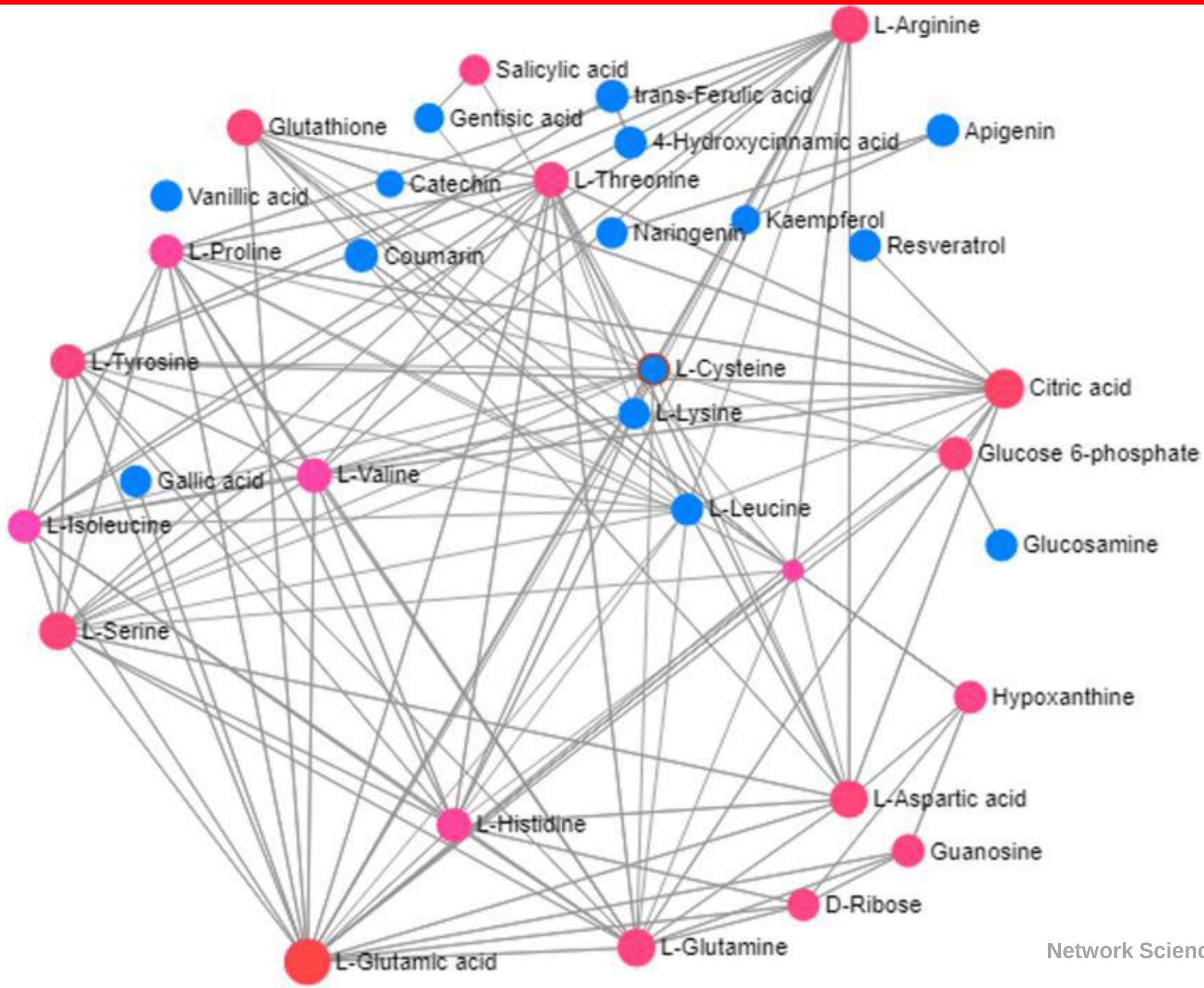
MOLECULAR NETWORKS



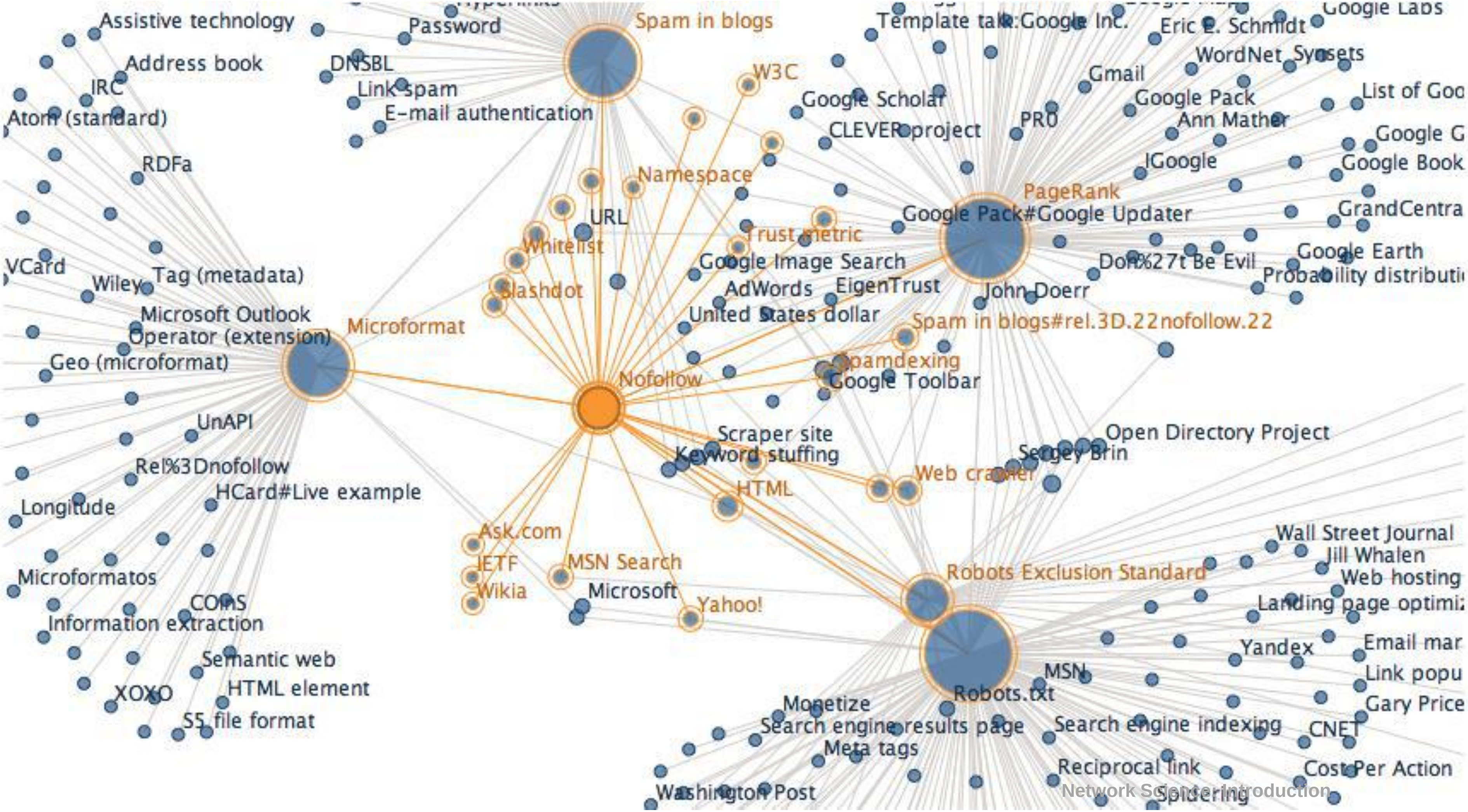
MOLECULAR NETWORKS

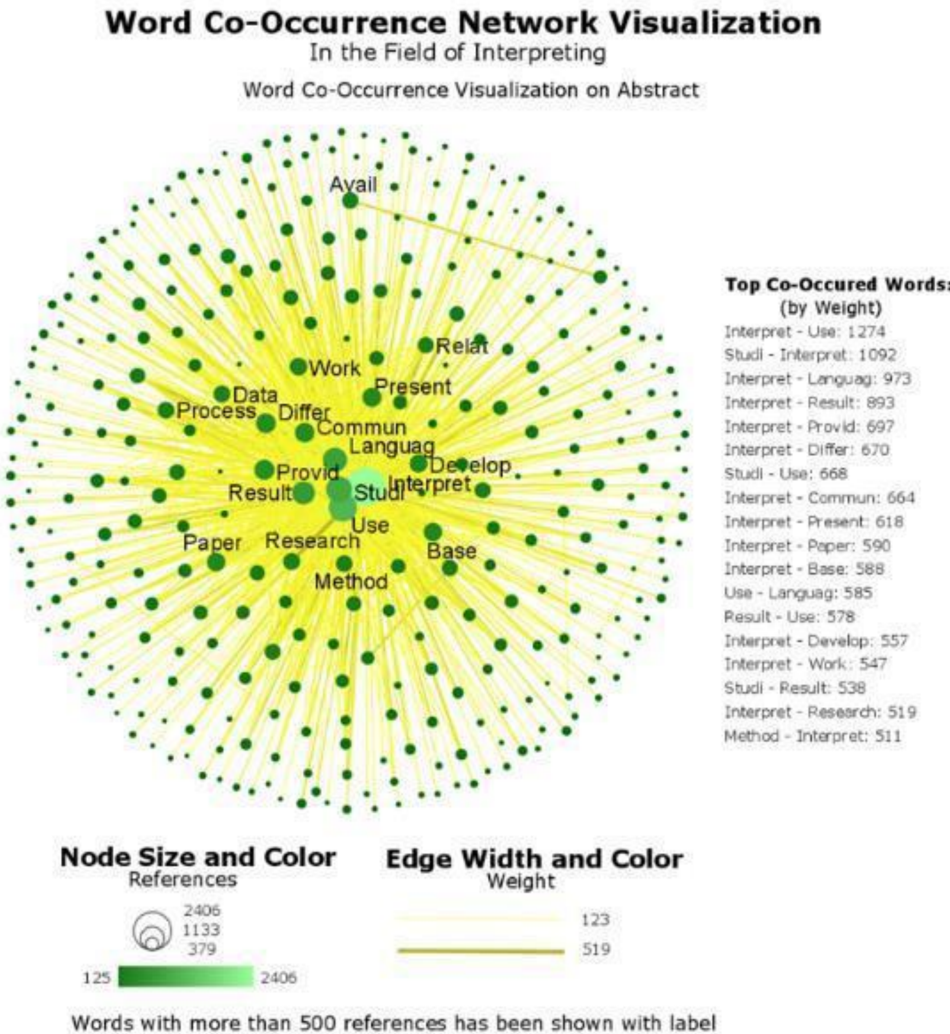


MOLECULAR NETWORKS



KNOWLEDGE, LANGUAGE, & SEMANTIC NETWORKS




Word Co-Occurrence Network Visualization
In the Field of Interpreting
Word Co-Occurrence Visualization on Abstract
Avail
Relat
Work
Present
Data
Process
Differ
Commun
Languag
Develop
Provid
Interpret
Result
Studi
Use
Paper
Research
Base
Method
Top Co-Occured Words:
(by Weight)
Interpret - Use: 1274
Studi - Interpret: 1092
Interpret - Languag: 973
Interpret - Result: 893
Interpret - Provid: 697
Interpret - Differ: 670
Studi - Use: 668
Interpret - Commun: 664
Interpret - Present: 618
Interpret - Paper: 590
Interpret - Base: 588
Use - Languag: 585
Result - Use: 578
Interpret - Develop: 557
Interpret - Work: 547
Studi - Result: 538
Interpret - Research: 519
Method - Interpret: 511
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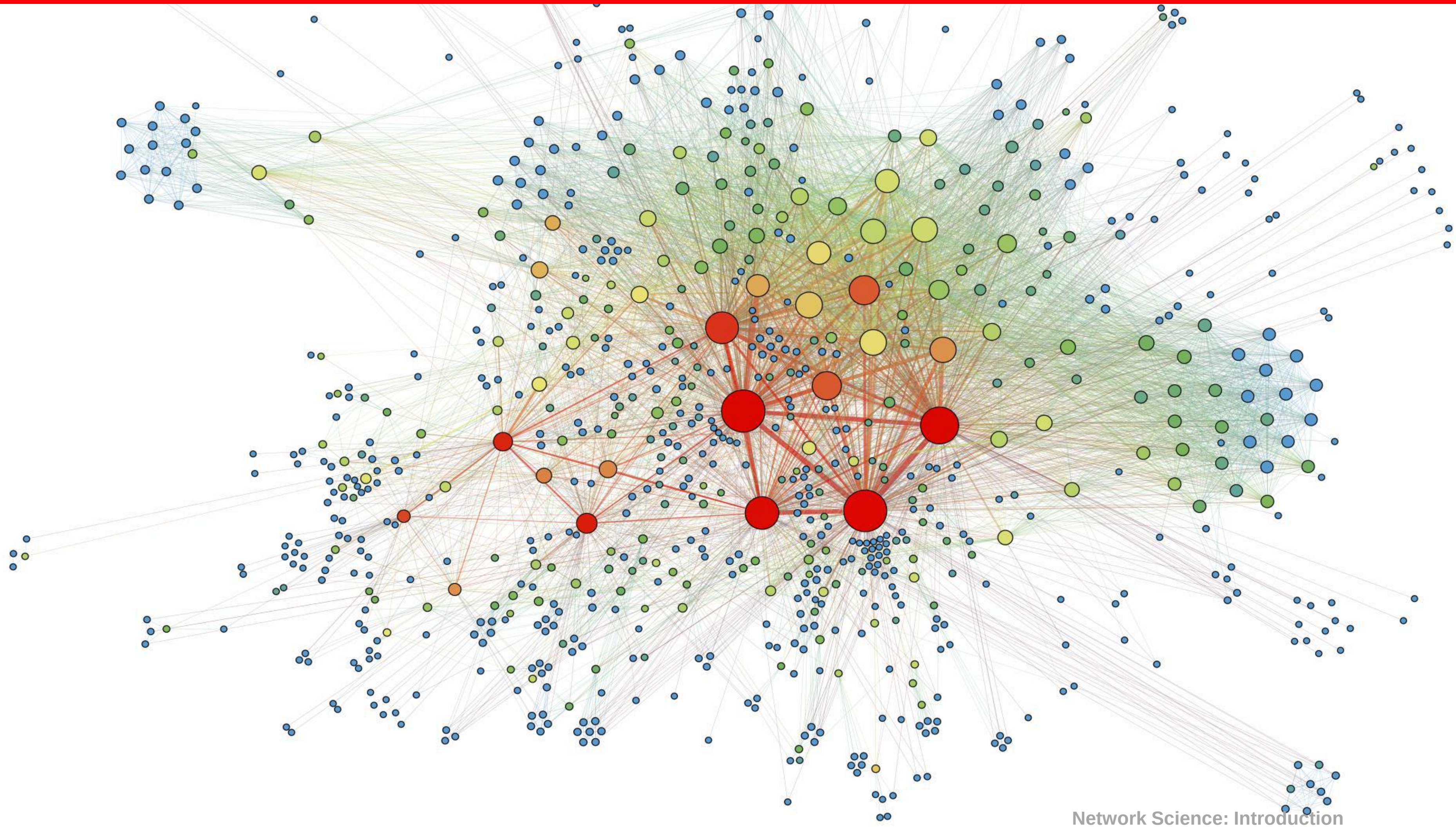
2406
Edge Width and Color
Weight
123
519
Words with more than 500 references has been shown with label

ABSTRACT NETWORKS



ABSTRACT NETWORKS

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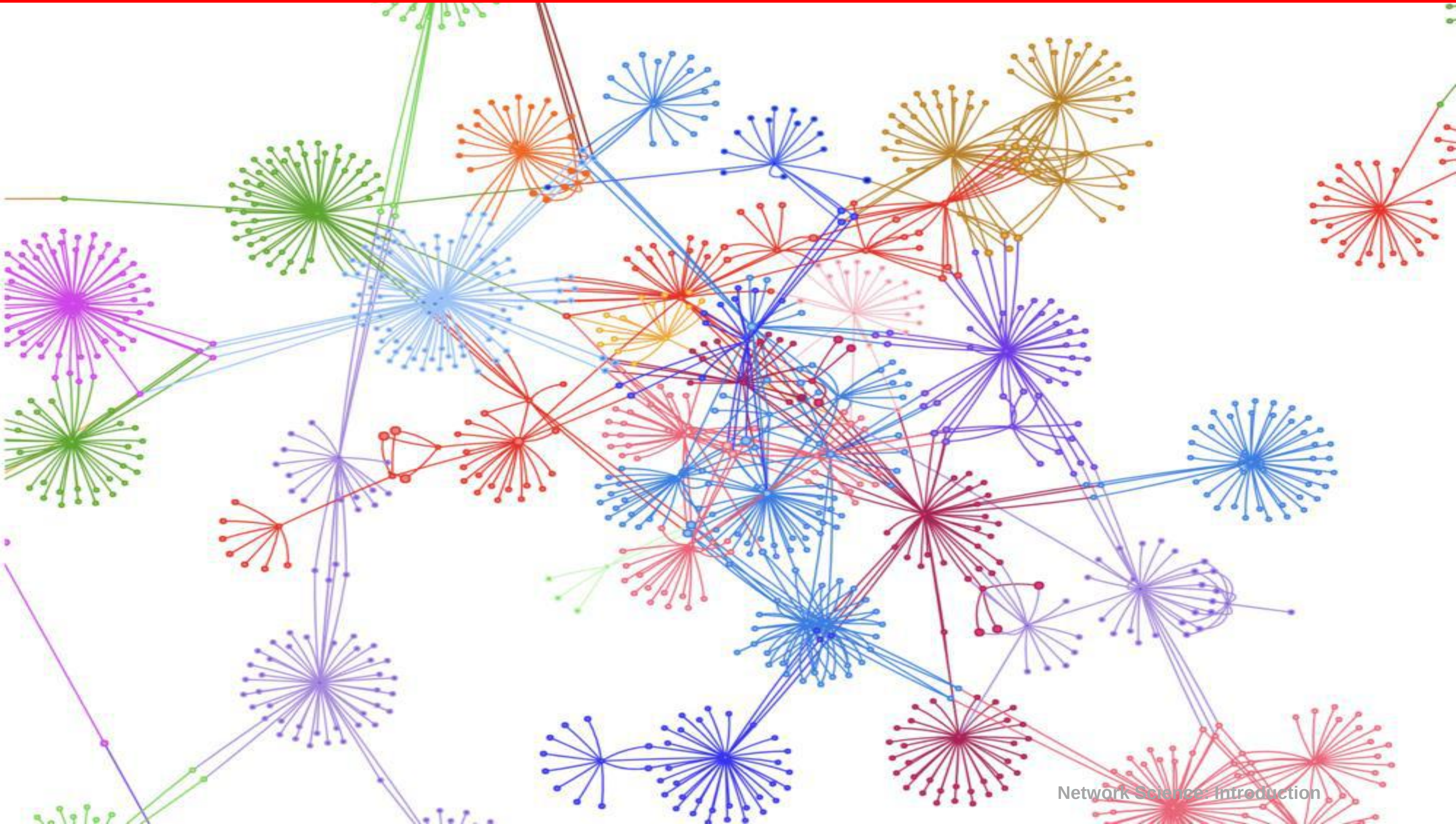


THE ROLE OF NETWORKS

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 HISTORY OF NETWORK ANALYSIS

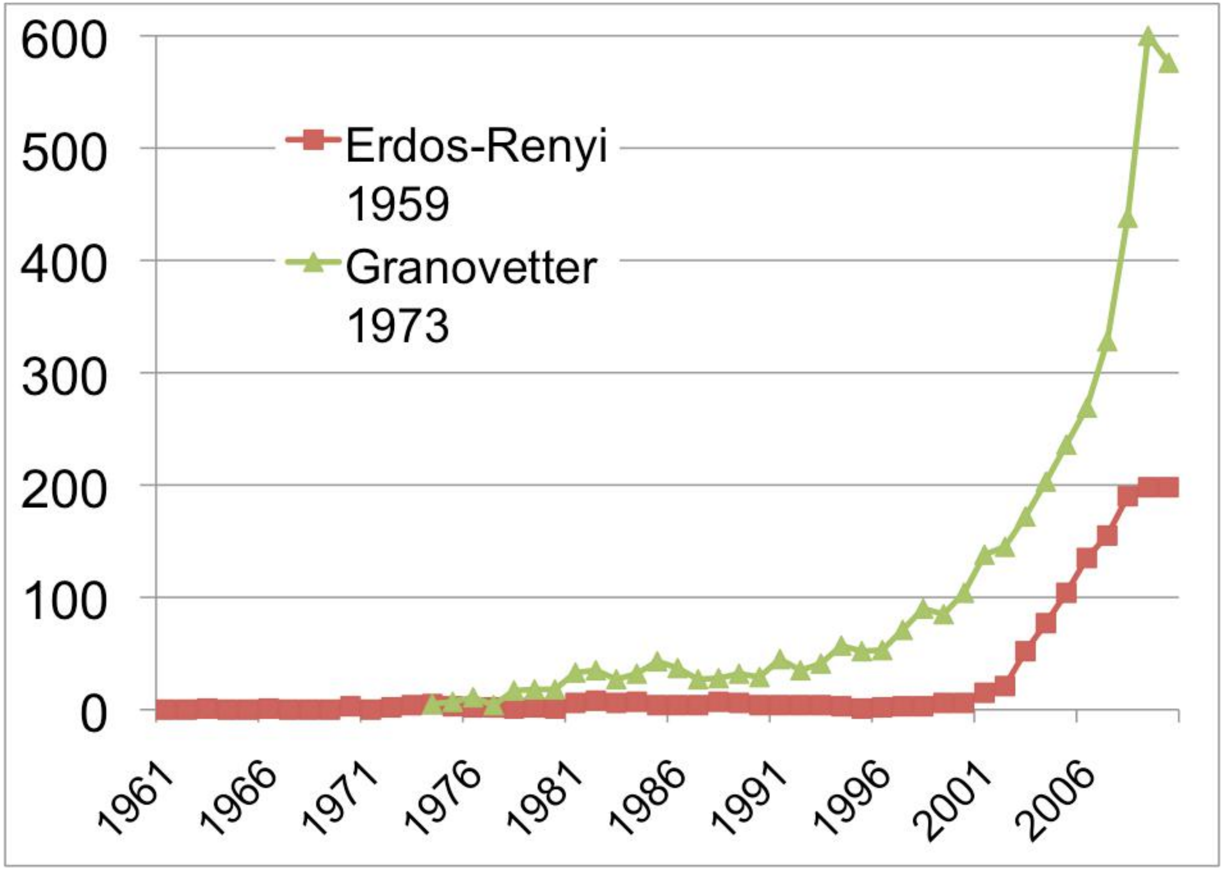
Graph theory: 1735, Euler

Social Network Research: 1930s, Moreno

Communication networks/internet: 1960s

Ecological Networks: May, 1979.

THE HISTORY OF NETWORK ANALYSIS



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.

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

ECONOMIC IMPACT

Google
Market Cap(2010 Jan 1):
$189 billion

Cisco Systems
networking gear Market cap (Jan 1, 2919):
$112 billion

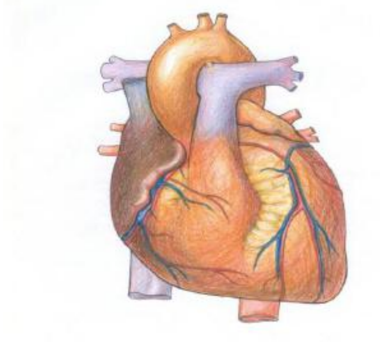
Facebook
market cap:
$50 billion

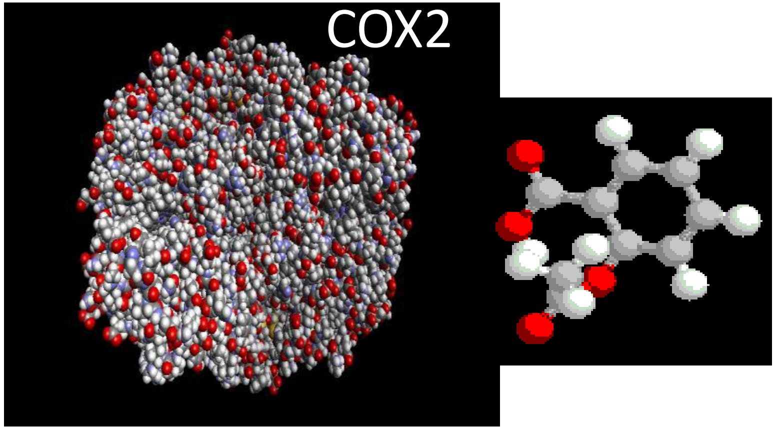
www.bizjournals.com/austin/news/2010/11/15/facebooks... - Cached

DRUG DESIGN, METABOLIC ENGINEERING:

Reduces
Inflammation
Fever
Pain

Prevents
Heart attack
Stroke



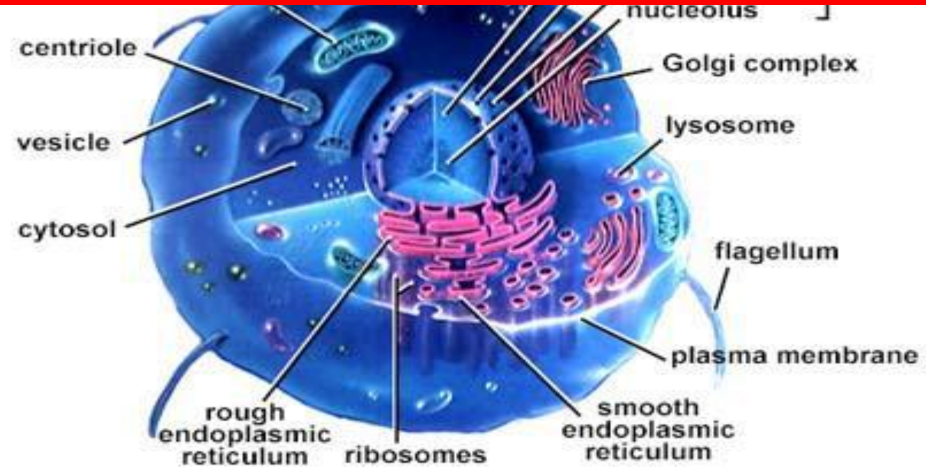


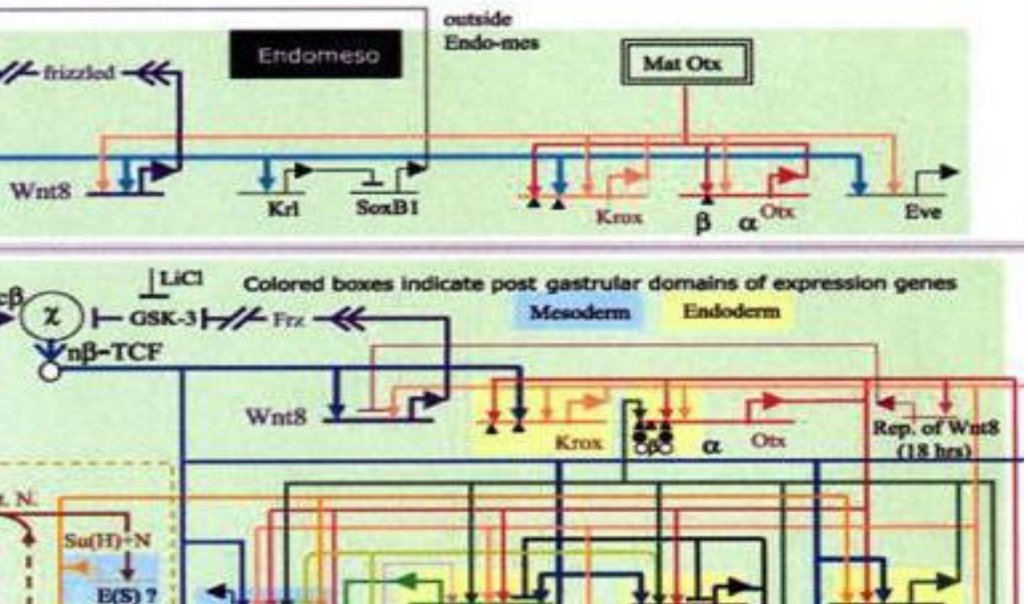
Reduces the risk of
Alzheimer's Disease

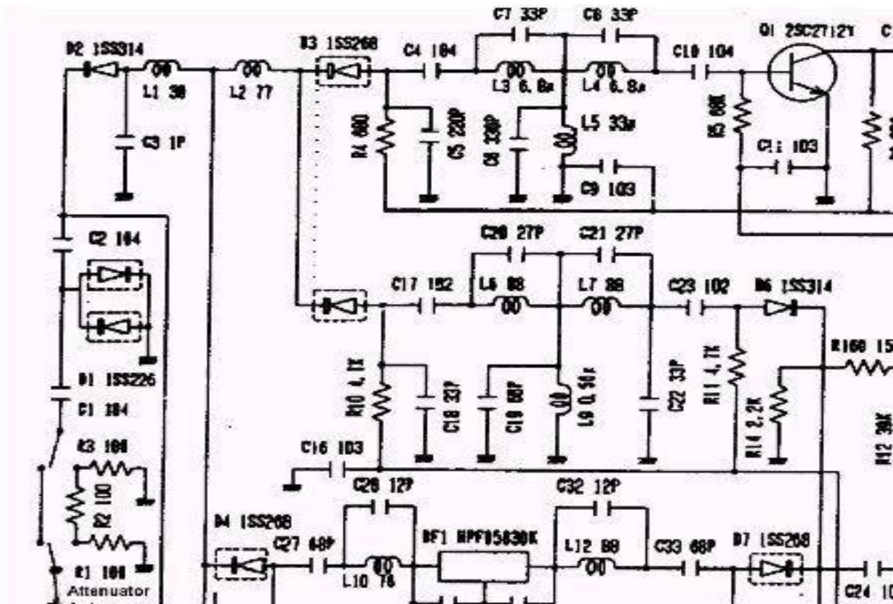
Reduces the risk of
breast cancer
ovarian cancers
colorectal cancer

Causes
Bleeding
Ulcer

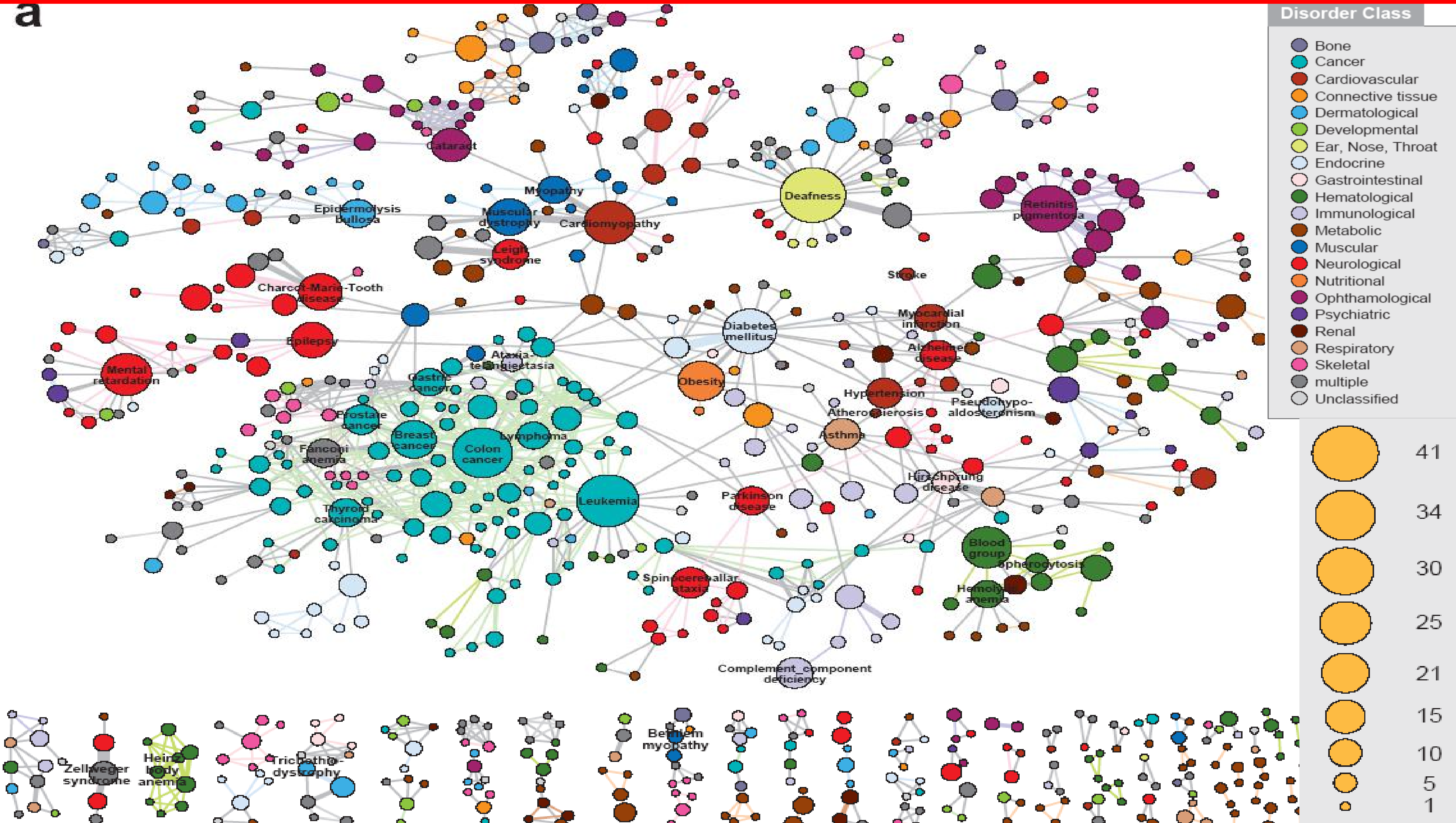
DRUG DESIGN, METABOLIC ENGINEERING:







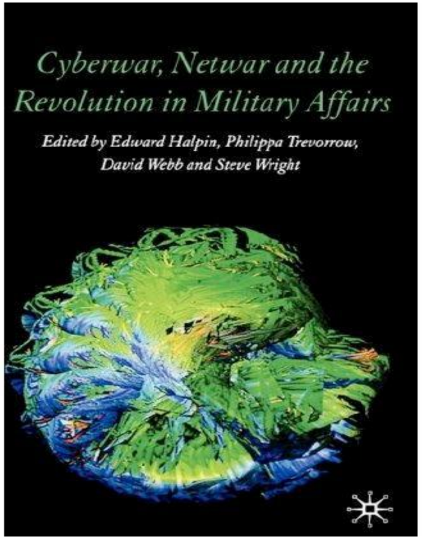
HUMAN DISEASE NETWORK

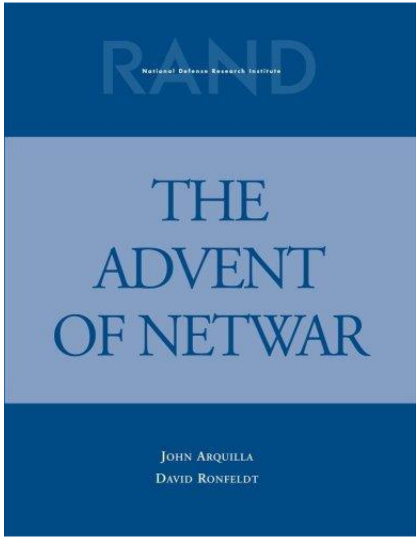


Network Biology/Network Medicine

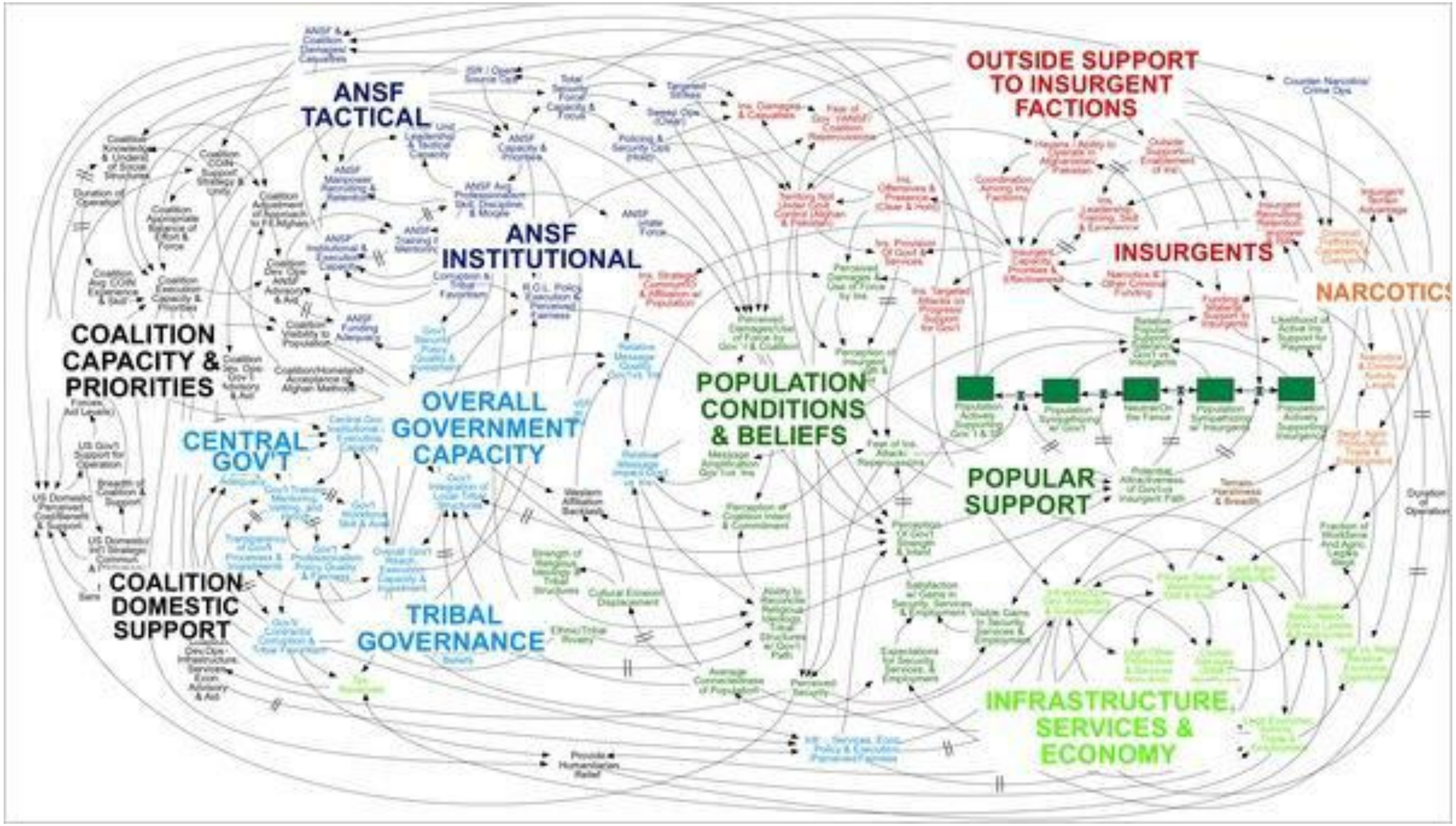
FIGHTING TERRORISM AND MILITARY

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



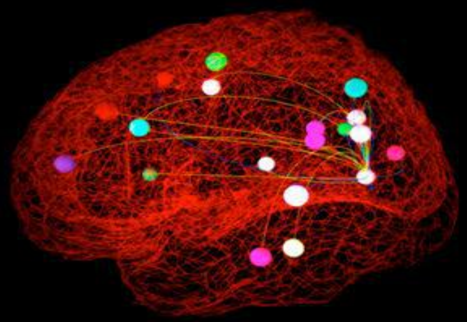


The network behind a military engagement

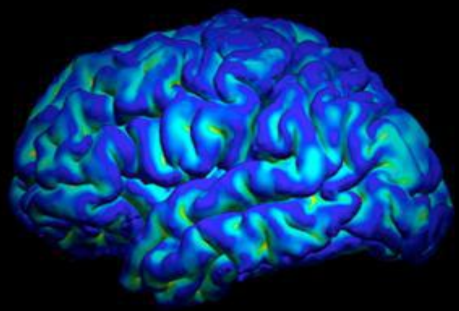


BRAIN RESEARCH

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/

SCIENTIFIC IMPACT

Complex systems and networks.

•**Science**:

Special Issue for the 10 year anniversary of Barabas i& Albert 1999 paper.

Original papers:

- 1998: Watts-Strogatz paper in the most cited **Nature** publication from 1998; highlighted by ISI as one of the ten most cited papers in physics in the decade after its publication.

- 1999: Barabasi and Albert paper is the most cited **Science** paper in 1999; highlighted by ISI as one of the ten most cited papers in physics in the decade after its publication.

- 2001: Pastor -Satorras and Vespignani is one of the two most cited papers among the papers published in 2001 by **Physical Review Letters**.

- 2002: Girvan-Newman is the most cited paper in 2002 **Proceedings of the National Academy of Sciences**.

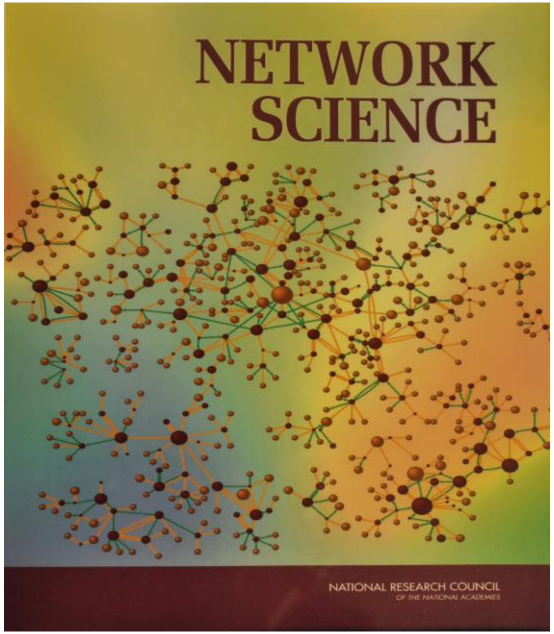
REVIEWS:

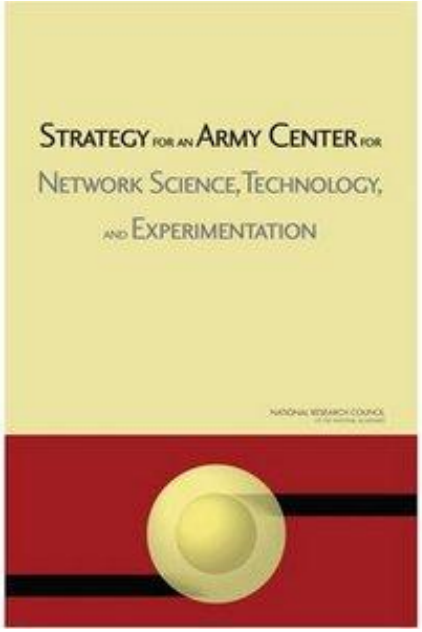
•The first review of network science by Albert and Barabasi, 2001) is the second most cited paper published in **Reviews of Modern Physics**, the highest impact factor physics journal, published since 1929. The most cited is *Chandaseklar*'s 1944 review on solar processes, but it will be surpassed by the end of 2012 by Albert *et al.*

•The SIAM review of Newman on network science is the most cited paper of any **SIAM journal**.

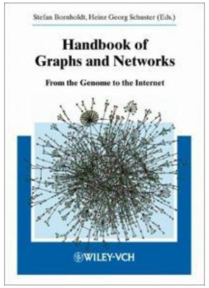
•BIOLOGY: "Network Biology", by Barabasi and Oltvai (2004) , is the second most cited paper in the history of **Nature Reviews Genetics**, the top review journal in genetics.

National Research Council

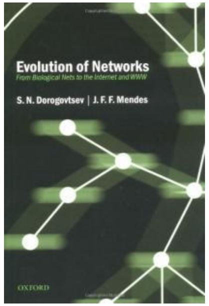




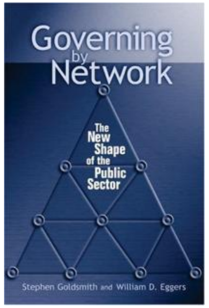
BOOKS



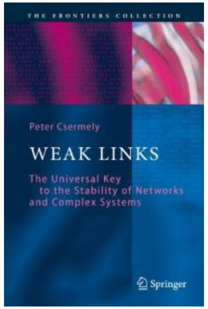
Handbook of Graphs and Networks: From the Genome to the Internet (Wiley-VCH, 2003).



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



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



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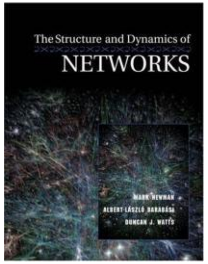
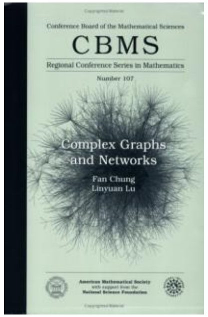


M. Newman, A.-L. Barabasi, D. J. Watts, The Structure and Dynamics of Networks: (Princeton Studies in Complexity) (Princeton University Press, 2006), rst edn.



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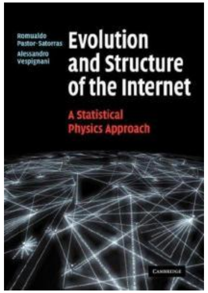
BOOKS



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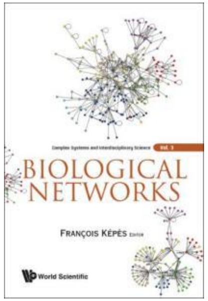
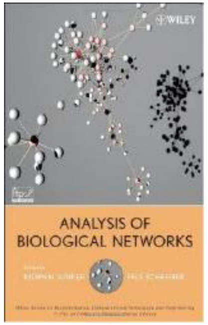
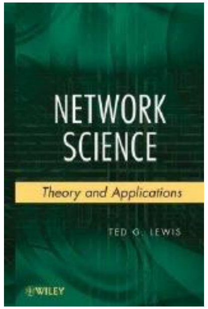


F. Kopos, Biological Networks (Complex Systems and Interdisciplinary Science) (World Scientic Publishing Company, 2007), rst edn.



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



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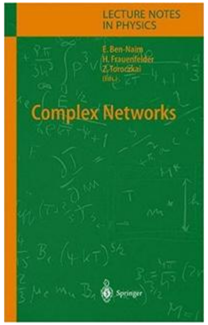
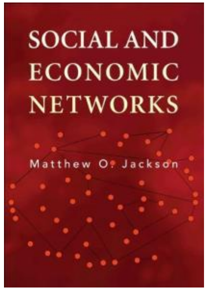
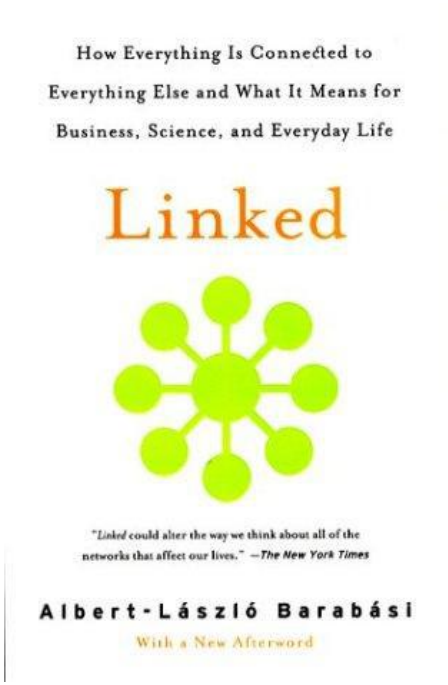


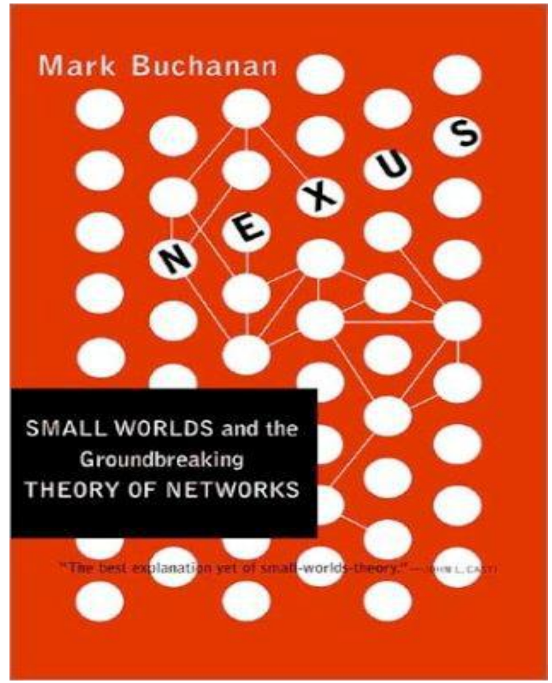
E. Ben Naim, H. Frauenfelder, Z.Torotzai, Complex Networks (Lecture Notes in Physics) (Springer, 2010), rst edn.

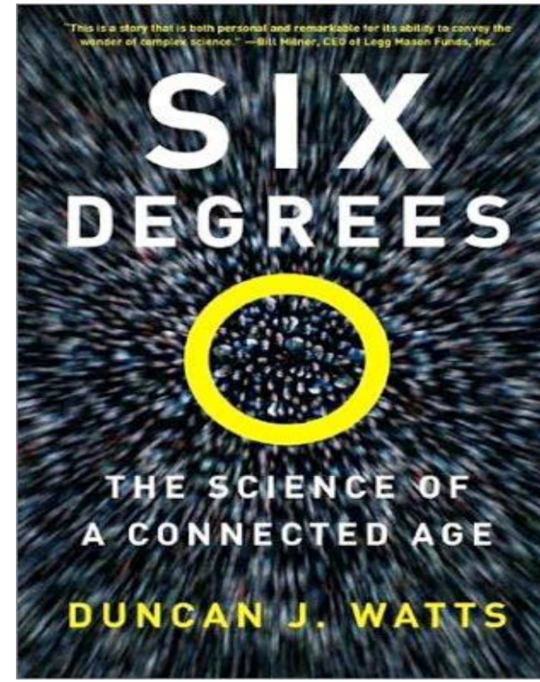


M. O. Jackson, Social and Economic Networks (Princeton University Press, 2010).

GENERAL AUDIENCE

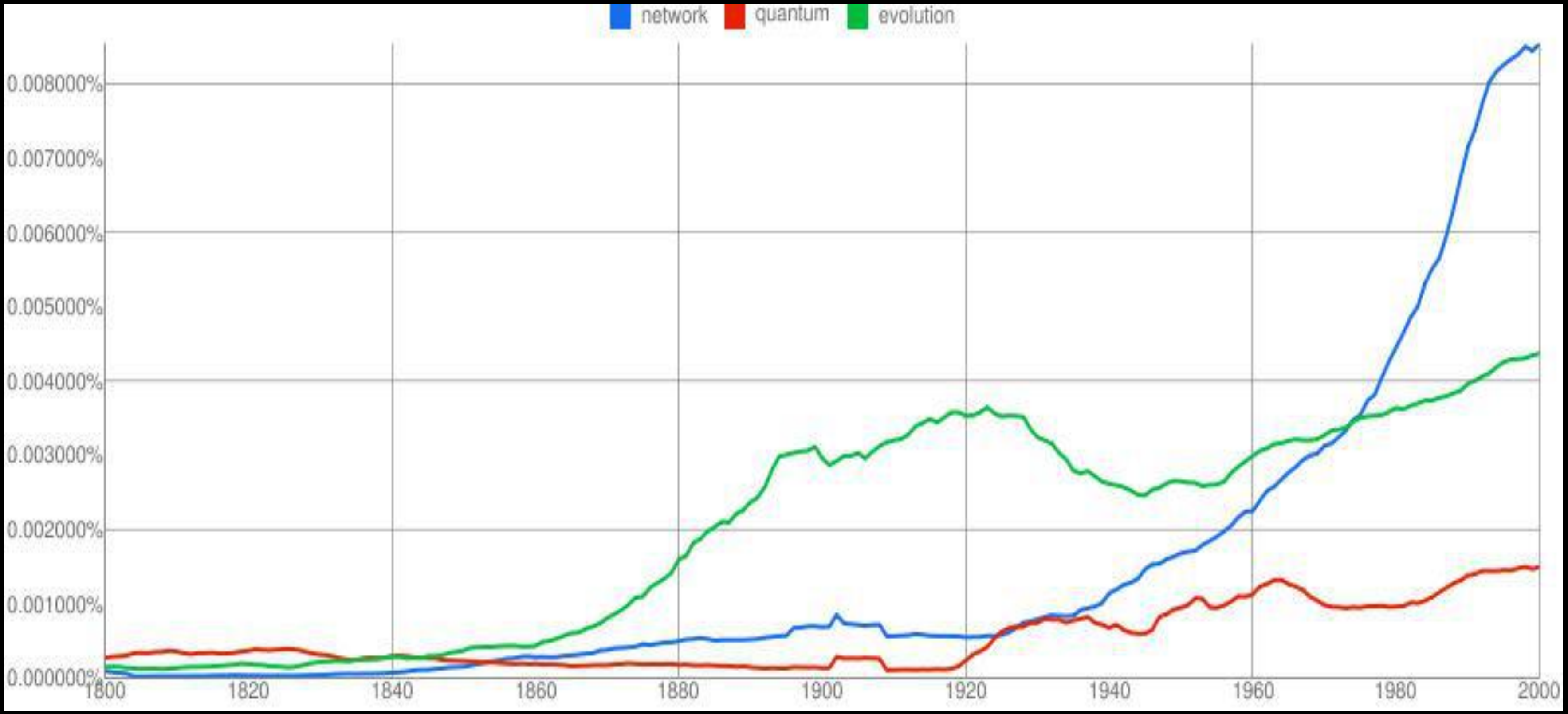






SUMMARY

Networks Awareness



If you were to understand the spread of diseases, **can you do it without networks?**

If you were to understand the WWW structure, searchability, etc, **hopeless without invoking the Web's topology.**

If you want to understand human diseases, **it is hopeless without considering the wiring diagram of the cell**.

Network Science

an interactive textbook

barabasi.com/**NetworkScienceBook/**

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Course Code	571
Course Name	Network Science
Credits	4
Course Offered to	UG/PG
Course Description	The objective of this course is to provide introduction to network science, an emerging interdisciplinary discipline with applications to various disciplines including social sciences, security and biomedical sciences. The student will be provided with understanding of fundamentals of network science and its applications. Through lectures, hands-on exercises and assignments, the student is expected to achieve a good grasp of the concepts and applications of network science.

Pre-requisites	
Pre-requisite (Mandatory)	Pre-requisite (Desirable)
None	Graph theory fundamentals, algorithms and programming (Desirable)

*Please insert more rows if required

Post Conditions			
CO1	**CO2**	**CO3**	**CO4**
Students are able to explain basic concepts of network science (random networks, scale free networks, network evolution, robustness and community structure).	Students are able to model and implement computation of network properties from empirical data.	Students are able to analyze and visualize networks.	Students are able to tweak and design algorithms to answer specific questions.

Weekly Lecture Plan			
Week Number	**Lecture Topic**	**COs Met**	**Assignment/Labs/Tutorial**
1	Complex systems and network models, Characteristics of network science, Societal impact, Examples of applications	CO1	3 hours (Homework)
2	Graph Theory: Graph theory and origin of networks, Adjacency matrix, Weighted Networks, Bipartite networks, Network Metrics	CO1, CO3	3+2 hours (Homework)
3	Graph Theory: Paths and distances, Connectedness, Clustering Coefficient	CO1, CO2, CO3	3+2 hours (Homework + Assignment-1)
4	Random networks: Random network model, Degree distribution, Small worlds	CO1, CO2, CO3	3+2 hours (Homework)
5	The Scale-Free Property-I: Power laws and scale-free networks, Hubs, The meaning of scale free, Universality, Ultra-small property	CO1, CO2	3+2 hours (Homework)
6	The Scale-Free Property-II: Role of degree exponent, Generating networks with arbitrary degree exponents	CO1, CO2, CO4	3+2 hours (Homework + Assignment-2)
7	The Barabasi-Albert Model-I: Growth and preferential attachment, The Barabasi-Albert model, Measuring preferrential attachment.	CO1, CO2, CO3	3+2 hours (Homework)
8	The Barabasi-Albert Model-II: Non-linear preferrential attachment, The origins of preferrential attachment,	CO1, CO2, CO3, CO4	3+2 hours (Homework + Mini Project)
9	Evolving Networks: The Bianconi-Barabasi model, Measuring fitness, Bose-Einstein condensation, Evolving networks	CO1, CO2, CO3	3+2 hours (Homework)
10	Degree Correlations: Assortativity and disassortativity, Measuring degree correlations, Generating correlated networks, The impact of degree correlations	CO1, CO2, CO3, CO4	3+2 hours (Homework)
11	Network Robustness: Percolation theory, Robustness of scale-free networks, Attack tolerence, Cascading failures, Modeling cascading failures, Building robustness	CO1, CO2	3+2 hours (Homework)
12	Communities: Basics of communities, Hierarchical clustering, Modularity, Overlapping communities, Testing communities, Characterizing communities	CO1, CO2	3+2 hours (Homework)
13	Spreading phenamena: Epidemic Modeling, Network epidemics, Contact networks, Beyond degree distribution, Immunization, Epidemic prediction	CO1	3+2 hours (Mini-Project Presentations)

*Please insert more rows if required

Weekly Lab Plan			
Week Number	**Laboratory Exercise**	**COs Met**	**Platform (Hardware/Software)**

*Please insert more rows if required

Assessment Plan	
Type of Evaluation	% Contribution in Grade
Mid-Sem	20
Assignments	30
Mini-Project	20
End-Sem	30

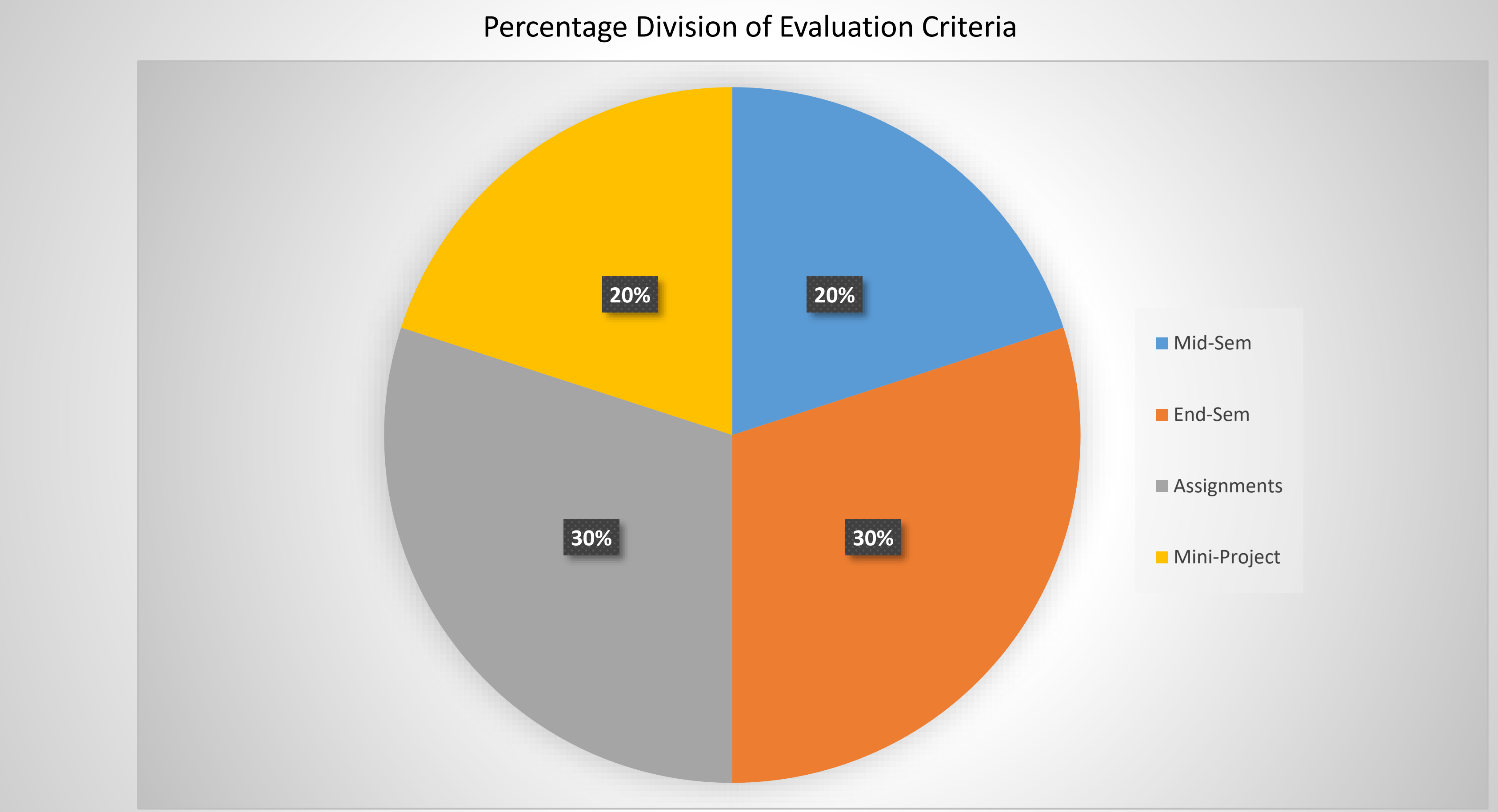
*Please insert more row for other type of Evaluation

Resource Material	
Type	**Title**
Textbook	Network Science, Albert-Laszlo Barabasi (Cambridge University Press)

Post Conditions

- Students are able to **explain** the basic concepts of network science.
- Students are able to **model and implement** computation of network properties from empirical data.
- Students are able to **analyze and visualize** networks.
- Students are able to **tweak and design** algorithms to answer specific questions.

Desirable Pre-requisites: Graph theory fundamentals, algorithms and programming.


Percentage Division of Evaluation Criteria
20%
20%
30%
30%
Mid-Sem
End-Sem
Assignments
Mini-Project

Lectures & Office Hours

When: Mondays and Wednesdays, 11am—12:30pm

Where: C201 (Lecture Hall Complex, Second Floor)

Office Hours:

Mondays and Wednesdays, 10am—11am

A305 (R&D Block)

- Network Science on Google Classroom

https://classroom.google.com/c/ODM3MzA5NzI5NjY5?cjc=voowtlok

Joining Code: voowtlok

- Go through the course description, evaluation.
- Apart from hands-on implementations in NetworkX/igraph, the course will have a mini-project