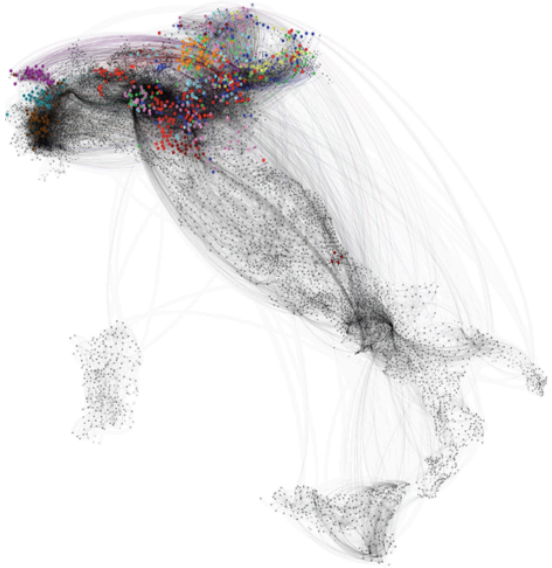
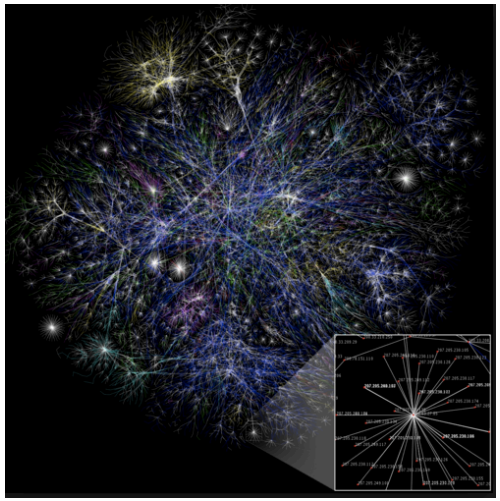
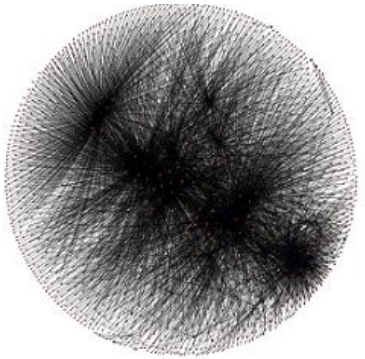
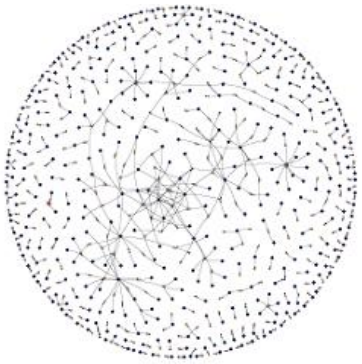


Complex Networks: Introduction

Ana Paula Couto
Computer Science Department
Universidade Federal de Minas Gerais







Complex systems

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

Stephen Hawking

Complex systems

- Lack of centralized control
- No linear relationships
- Memory
- Multiple scales of time events
- Phenomena with complex behavior: social, technological, weather, and so on.

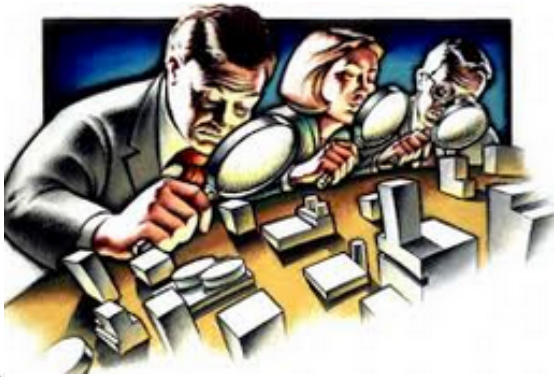
What is the complex definition?

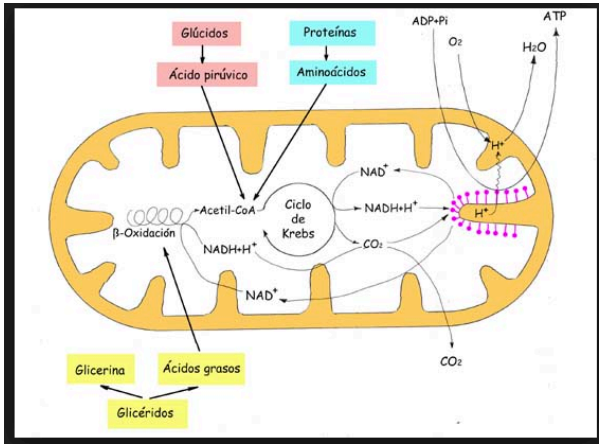
Complex: (Latin = with + fold/weave (com + plex))

Adjective

- Made up of multiple parts; intricate or detailed.
- Not simple or straightforward.

Complex systems





What is the network definition?

net•work |ˈnetˌwərk|

noun

1 an arrangement of intersecting horizontal and vertical lines.

- a complex system of roads, railroads, or other transportation routes : *a network of railroads.*

2 a group or system of interconnected people or things : *a trade network.*

- a group of people who exchange information, contacts, and experience for professional or social purposes : *a support network.*
- a group of broadcasting stations that connect for the simultaneous broadcast of a program : *the introduction of a second TV network* | [as adj.] *network television.*
- a number of interconnected computers, machines, or operations : *specialized computers that manage multiple outside connections to a network* | *a local cellular phone network.*
- a system of connected electrical conductors.

verb [trans.]

connect as or operate with a network : *the stock exchanges have proven to be resourceful in networking these deals.*

- link (machines, esp. computers) to operate interactively : [as adj.] (**networked**) *networked workstations.*
- [intrans.] [often as n.] (**networking**) interact with other people to exchange information and develop contacts, esp. to further one's career : *the skills of networking, bargaining, and negotiation.*

What is the network definition?

verb [trans.]
connect as or operate with a network : *the stock exchanges have proven to be resourceful in networking these deals.*

- link (machines, esp. computers) to operate interactively : [as adj.] (**networked**) *networked workstations.*
- [intrans.] [often as n.] (**networking**) interact with other people to exchange information and develop contacts, esp. to further one's career : *the skills of networking, bargaining, and negotiation.*

What is the network definition?

network

noun

1 *a network of arteries* WEB, lattice, net, matrix, mesh, crisscross, grid, reticulum, reticulation; Anatomy plexus.

2 *a network of lanes* MAZE, labyrinth, warren, tangle.

3 *a network of friends* SYSTEM, complex, nexus, web, webwork.

Complex networks

Behind each complex system, there is an intricate network that encodes the interactions between the system's components.

Network Science Book – Albert Barabasi

Complex Networks

- A set of complex systems can be modeled as complex networks, with physical or abstract interactions

- Networks are the heart of some of the most revolutionary technologies, empowering everything from Google to Facebook, CISCO, and Twitter.

Complex networks

It is increasingly clear that we will never understand complex systems unless we gain a deep understanding of the networks behind them.

Network Science Book – Albert Barabasi

Complex networks

- Despite the amazing diversity in form, size, nature, age, most networks observed in nature, society, and technology are driven by common organizing principles.

- Scientific explosion on network science field (first decade of the 21st century)!

Network science

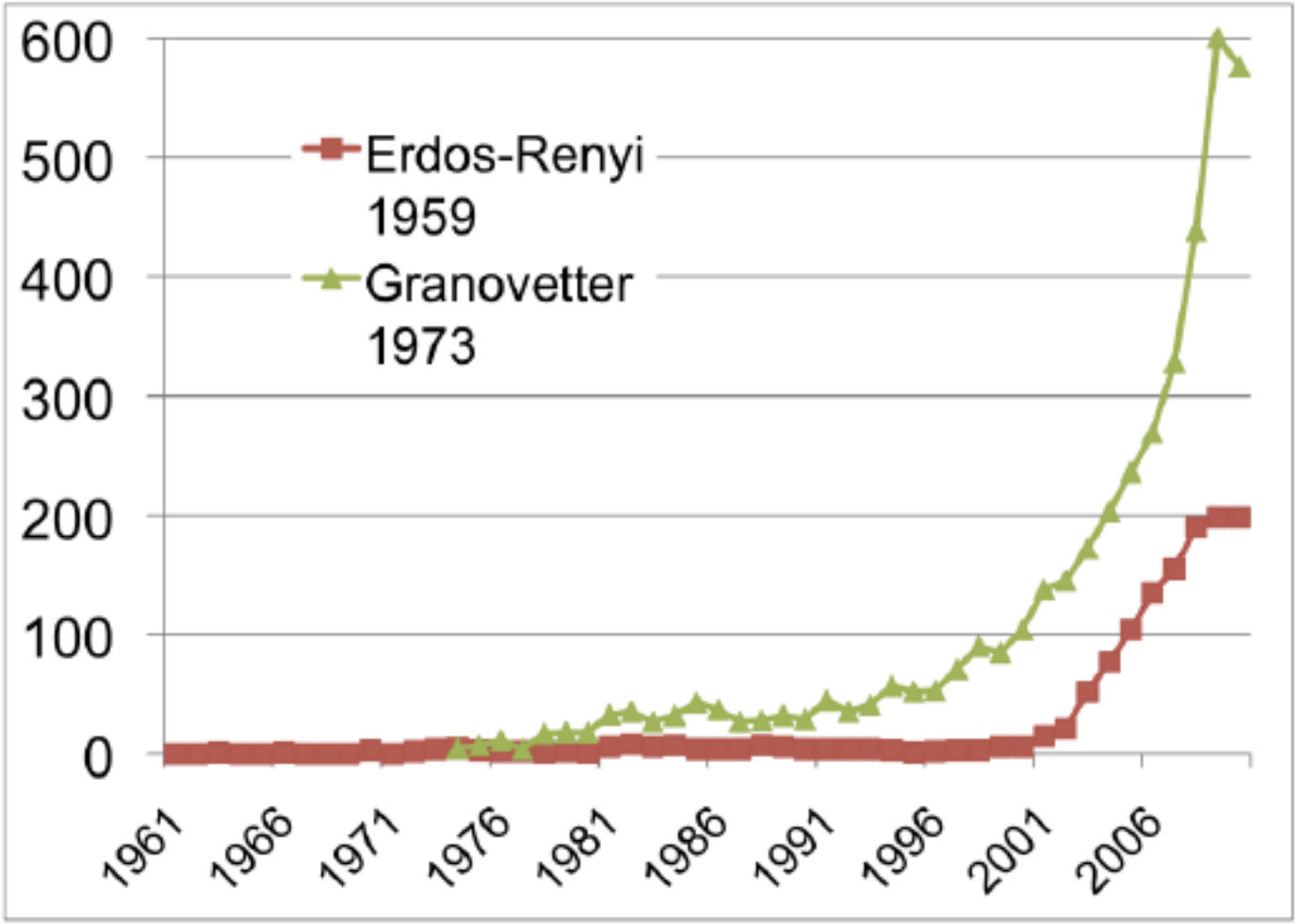


Image 1.5

The emergence of network science.

Network science

- Erdos-Renyi [1959]

On random graphs I.

Dedicated to O. Varga, at the occasion of his 50th birthday.

By P. ERDŐS and A. RÉNYI (Budapest).

Let us consider a "random graph" $\Gamma_{n,N}$ having n possible (labelled) vertices and N edges; in other words, let us choose at random (with equal probabilities) one of the $\binom{\binom{n}{2}}{N}$ possible graphs which can be formed from the n (labelled) vertices $P_1, P_2, \ldots, P_n$ by selecting N edges from the $\binom{n}{2}$ possible edges $\overline{P_iP_j}$ $(1 \leqq i < j \leqq n)$. Thus the effective number of vertices of $\Gamma_{n,N}$ may be less than n, as some points P_i may be not connected in $\Gamma_{n,N}$ with any other point P_j; we shall call such points P_i *isolated* points. We consider the isolated points also as belonging to $\Gamma_{n,N}$. $\Gamma_{n,N}$ is called completely connected if it effectively contains all points $P_1, P_2, \ldots, P_n$ (i, e. if it has no isolated points) and is connected in the ordinary sense. In the present paper we consider asymptotic statistical properties of random graphs for $n \to +\infty$. We shall deal with the following questions:

1. What is the probability of $\Gamma_{n,N}$ being completely connected?
2. What is the probability that the greatest connected component (subgraph) of $\Gamma_{n,N}$ should have effectively $n-k$ points? $(k=0, 1, \ldots)$.
3. What is the probability that $\Gamma_{n,N}$ should consist of exactly $k+1$ connected components? $(k=0, 1, \ldots)$.
4. *If the edges of a graph with n vertices are chosen successively so* that after each step every edge which has not yet been chosen has the same probability to be chosen as the next, and if we continue this process until the graph becomes completely connected, what is the probability that the number of necessary steps ν will be equal to a given number l?

Network science

- Granovetter[1973]

The Strength of Weak Ties[1]

Mark S. Granovetter
Johns Hopkins University

Analysis of social networks is suggested as a tool for linking micro and macro levels of sociological theory. The procedure is illustrated by elaboration of the macro implications of one aspect of small-scale interaction: the strength of dyadic ties. It is argued that the degree of overlap of two individuals' friendship networks varies directly with the strength of their tie to one another. The impact of this principle on diffusion of influence and information, mobility opportunity, and community organization is explored. Stress is laid on the cohesive power of weak ties. Most network models deal, implicitly, with strong ties, thus confining their applicability to small, well-defined groups. Emphasis on weak ties lends itself to discussion of relations *between* groups and to analysis of segments of social structure not easily defined in terms of primary groups.

Network science

- Granovetter[1973]

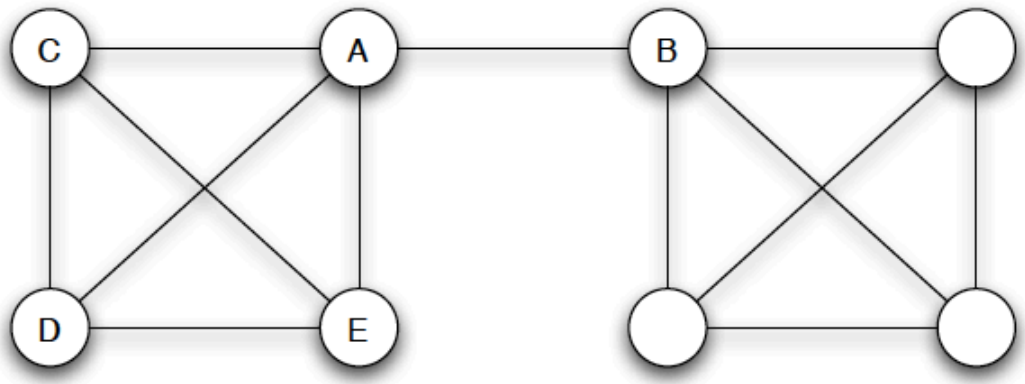


Figure 3.3: The A-B edge is a *bridge*, meaning that its removal would place A and B in distinct connected components. Bridges provide nodes with access to parts of the network that are unreachable by other means.

Network science seminal papers

"Collective dynamics of 'small-world' networks" [21]

- Watts and Strogatz
  Nature, 1998
- ≈ 4100 citations (as of January 18, 2010)
- Over 1100 citations in 2008 alone.

"Emergence of scaling in random networks" [2]

- Barabási and Albert
  Science, 1999
- ≈ 4400 citations (as of January 18, 2010)
- Over 1100 citations in 2008 alone.

Network science seminal papers

Letters to Nature

Nature **393**, 440-442 (4 June 1998) | doi:10.1038/30918; Received 27 November 1997; Accepted 6 April 1998

Collective dynamics of 'small-world' networks

Duncan J. Watts[2] & Steven H. Strogatz[1]

1. Department of Theoretical and Applied Mechanics, KimballHall, Cornell University, Ithaca, New York 14853, USA
2. Present address: Paul F. Lazarsfeld Center for the Social Sciences, Columbia University, 812 SIPA Building, 420 W118 St, New York, New York 10027, USA.

Correspondence to: Duncan J. Watts[2] Correspondence and requests for materials should be addressed to D.J.W. (e-mail: Email: djw24@columbia.edu).

Networks of coupled dynamical systems have been used to model biological oscillators[1, 2, 3, 4], Josephson junction arrays[5],[6], excitable media[7], neural networks[8, 9, 10], spatial games[11], genetic control networks[12] and many other self-organizing systems. Ordinarily, the connection topology is assumed to be either completely regular or completely random. But many biological, technological and social networks lie somewhere between these two extremes. Here we explore simple models of networks that can be tuned through this middle ground: regular networks 'rewired' to introduce increasing amounts of disorder. We find that these systems can be highly clustered, like regular lattices, yet have small characteristic path lengths, like random graphs. We call them 'small-world' networks, by analogy with the small-world phenomenon[13],[14] (popularly known as six degrees of separation[15]). The neural network of the worm *Caenorhabditis elegans*, the power grid of the western United States, and the collaboration graph of film actors are shown to be small-world networks. Models of dynamical systems with small-world coupling display enhanced signal-propagation speed, computational power, and synchronizability. In particular, infectious diseases spread more easily in small-world networks than in regular lattices.

Network science seminal papers

Emergence of Scaling in Random Networks

Albert-László Barabási*, Réka Albert

+ Author Affiliations

Science 15 Oct 1999:
Vol. 286, Issue 5439, pp. 509-512
DOI: 10.1126/science.286.5439.509

Article | Figures & Data | Info & Metrics | eLetters | PDF

You are currently viewing the abstract. *View Full Text*

Abstract

Systems as diverse as genetic networks or the World Wide Web are best described as networks with complex topology. A common property of many large networks is that the vertex connectivities follow a scale-free power-law distribution. This feature was found to be a consequence of two generic mechanisms: (i) networks expand continuously by the addition of new vertices, and (ii) new vertices attach preferentially to sites that are already well connected. A model based on these two ingredients reproduces the observed stationary scale-free distributions, which indicates that the development of large networks is governed by robust self-organizing phenomena that go beyond the particulars of the individual

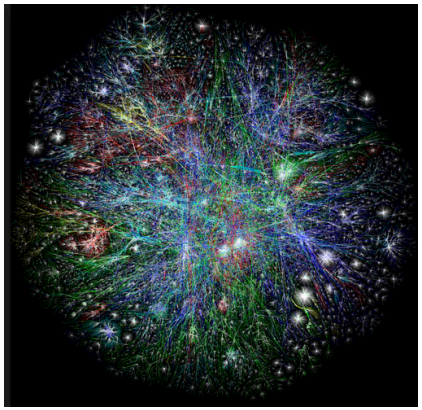
Are we dealing with a complex network?

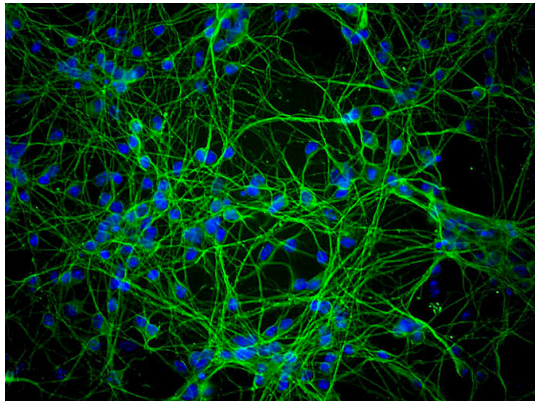
- Large number of entities (most of the cases)
- Relationships are dynamic and hard to describe and understand (what happened for having a given network formation?)
- Complex networks: social, technological, biological, economic

EXAMPLES

Physical networks

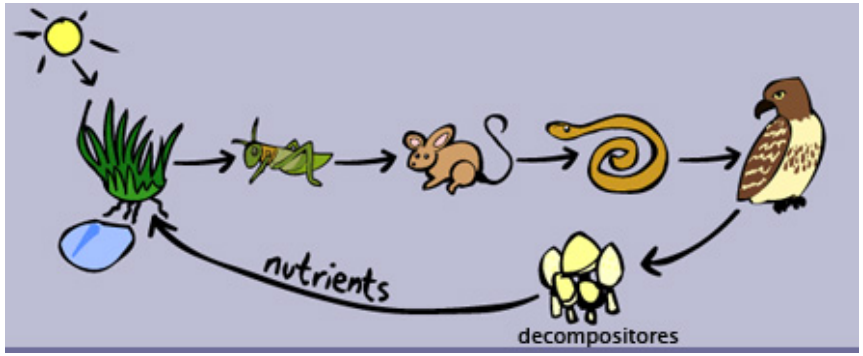
- Neural
- Internet
- Roads
- Power grid

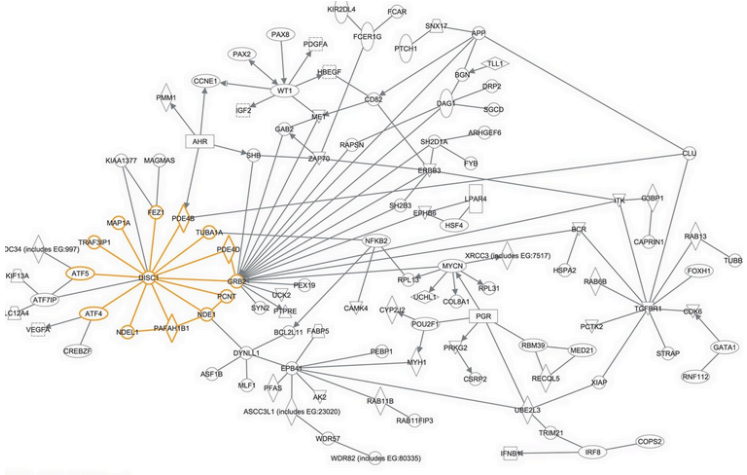




Networks with interactions

- Biochemical
- Gene-Protein
- Food web
- WWW





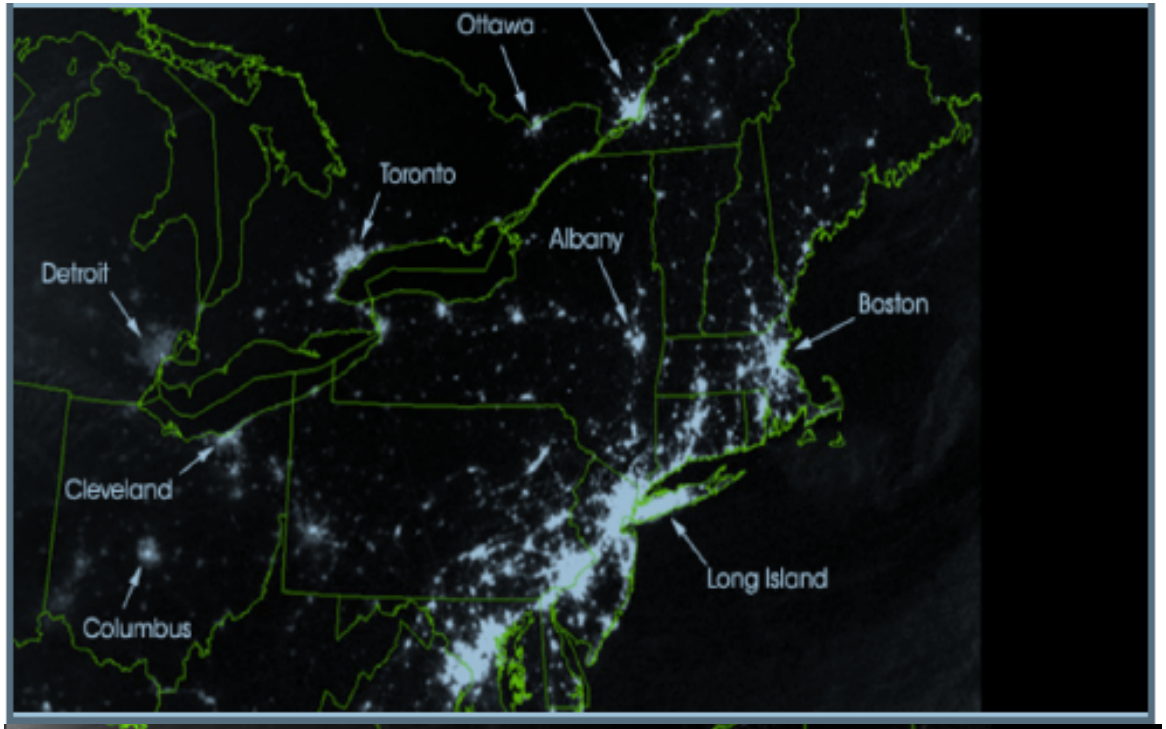
Social networks

- Friendship
- Acquaintance
- Co-works
- Co-authors

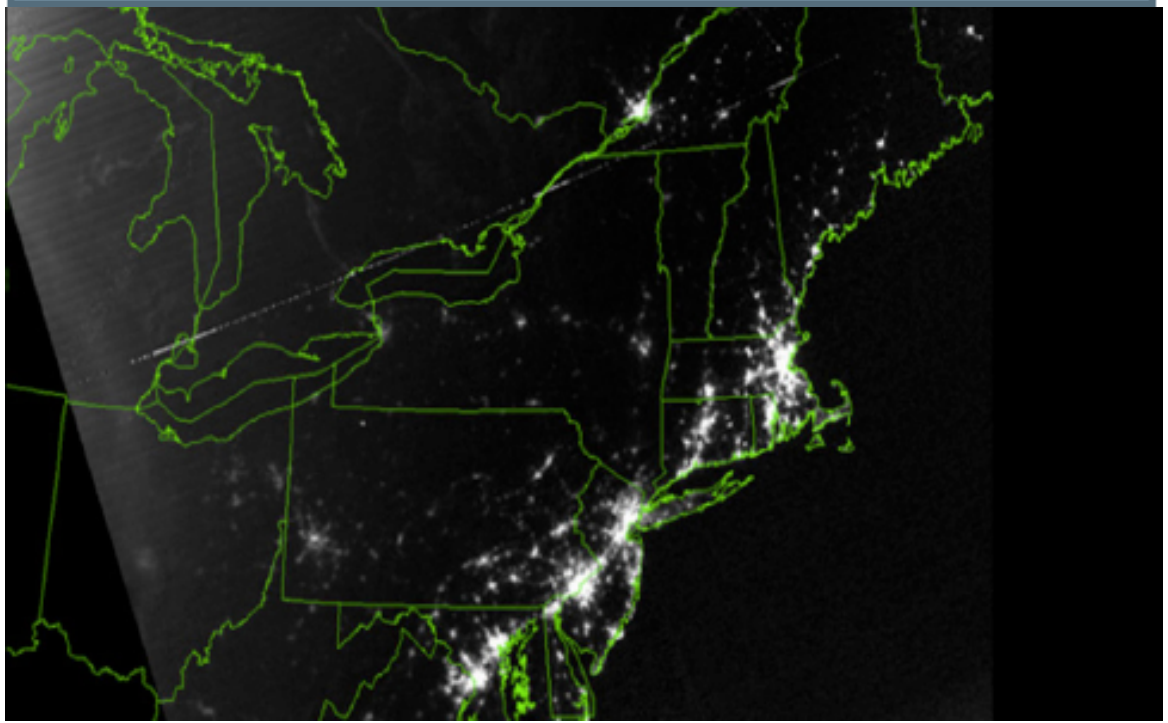
VULNERABILITY DUE TO INTERCONNECTIVITY

2003 NORTH AMERICAN BLACKOUT

- Satellite image of August 13, 2003:9:29pm



- Satellite image of August 14,2003:9:14pm



Network Science Book – Albert Barabasi

2003 North American Blackout

- At a first look: images are almost the same
- Second image: Light in several regions (Toronto, Detroit, Cleveland, Columbus) have disappeared
- 2003 Blackout: 45M people in 8 US states and 10M in Ontario without power

2003 North American Blackout

- Cascading Failure Phenomenon: when network acts as a transportation system, a local failure shifts loads to other nodes.

- It can occur in most complex systems:
  - Internet: traffic is rerouted to bypass malfunctioning routers
  - 2009-201 financial meltdown, when the US credit crisis paralyzed the economy of the globe

What is the picture of relationships?

FRIENDSHIP NETWORK USA SCHOOL

Friendship network

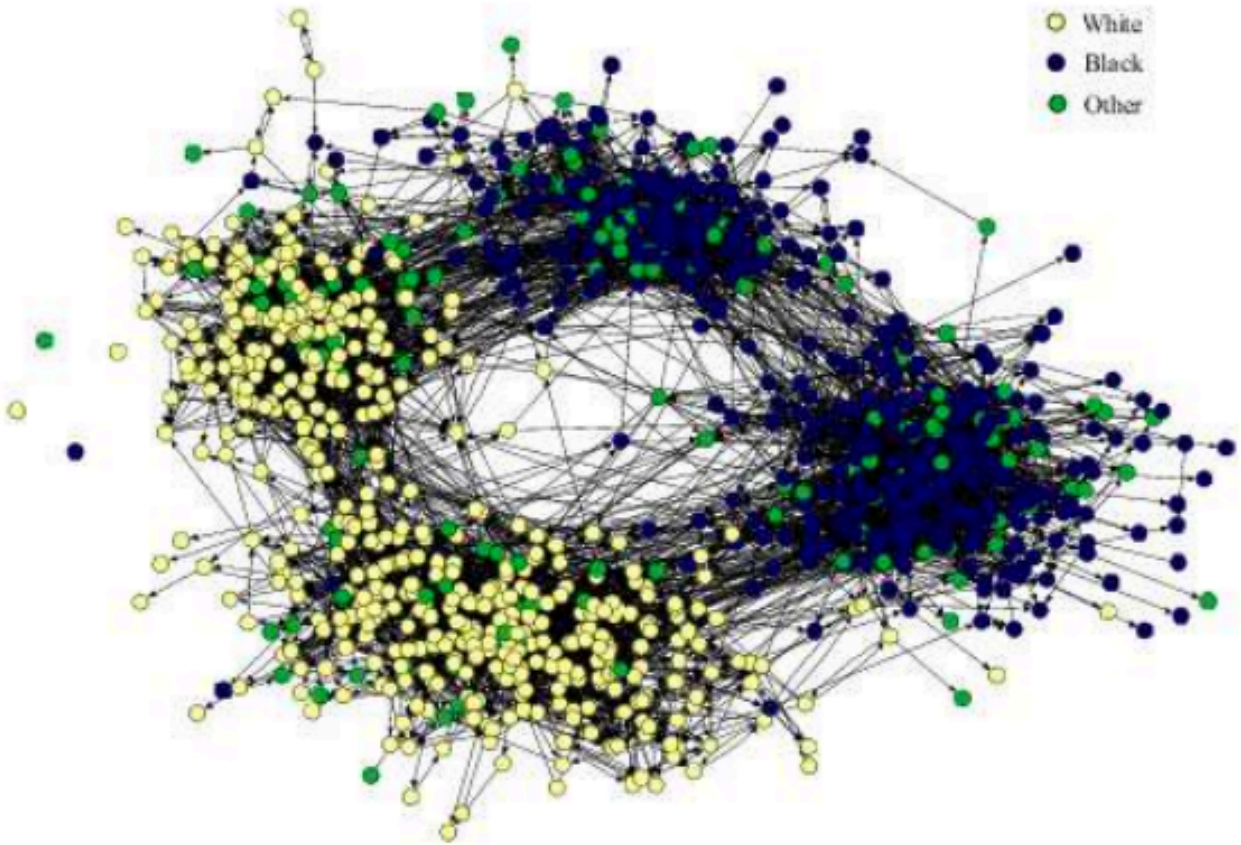


FIG. 8 Friendship network of children in a US school. Friendships are determined by asking the participants, and hence are directed, since A may say that B is their friend but not *vice versa*. Vertices are color coded according to race, as marked, and the split from left to right in the figure is clearly primarily along lines of race. The split from top to bottom is between middle school and high school, i.e., between younger and older children. Picture courtesy of James Moody.

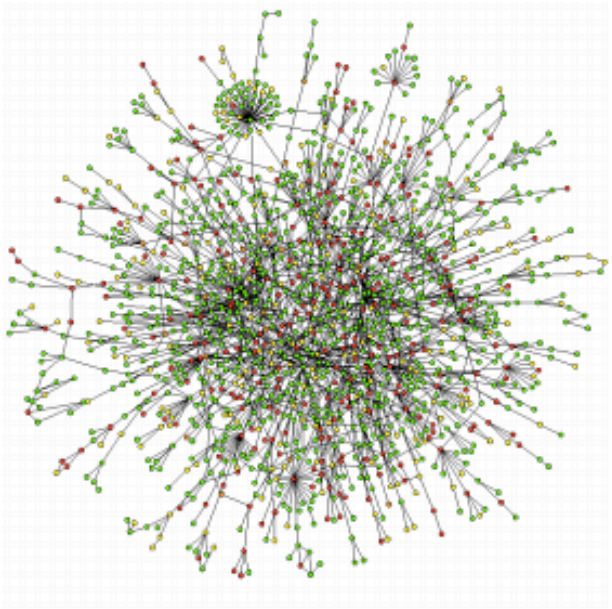
M. E. J. Newman, The structure and function of complex networks

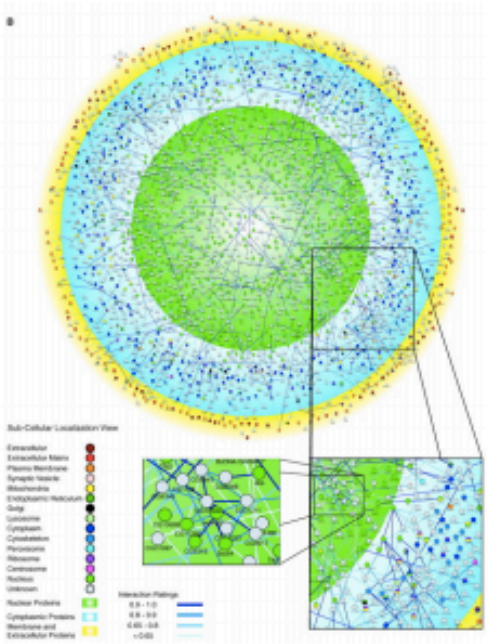
Biological Networks

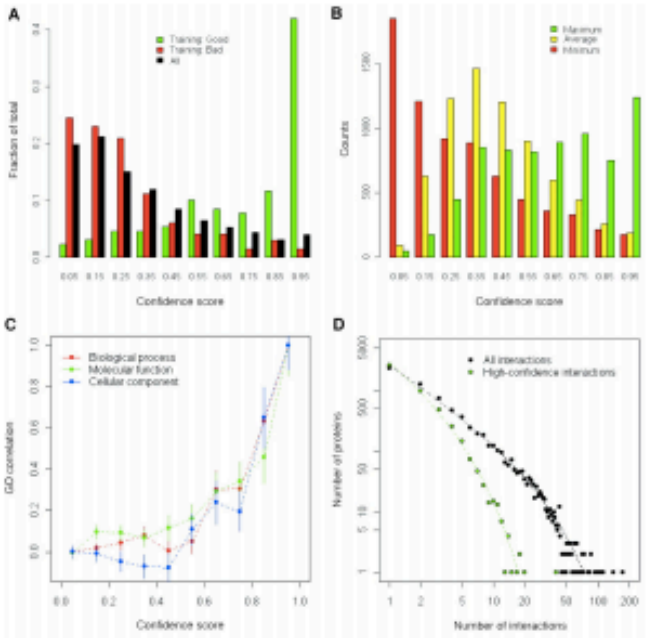
PROTEIN INTERACTION NETWORK

Protein interaction network

Protein interact in various ways during cell life.







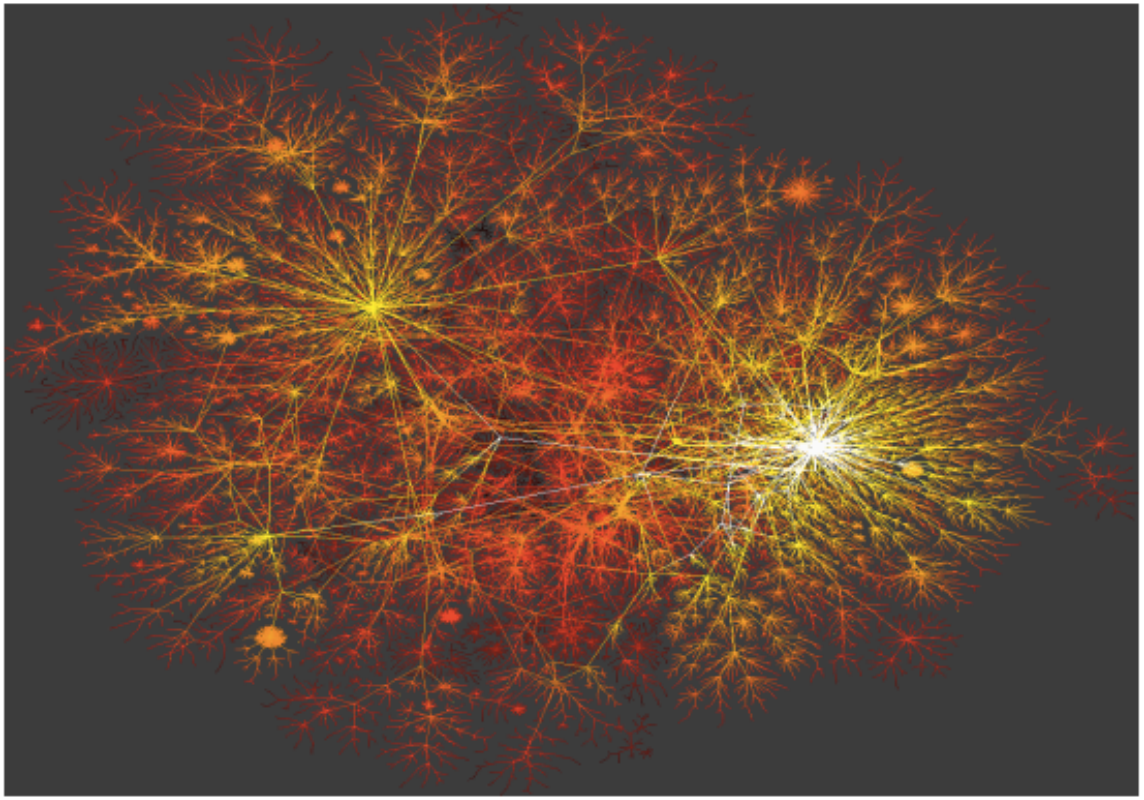
Uetz et al. *Nature* **403** 623 (2000)
H. Jeong et al. *Nature*, **411,** 41 (2002)
Giot et al. *Science* **302,** 1727 (2003)
Rual et al. *Nature* **437**, *1173 (2005)*
Ramani et al. *Molecular Biology* **4,** 180 (2008)

http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf

Technological Networks

INTERNET

Internet



Traditionally the analysis of the Internet structure is made by means of *traceroutes.* That is to say, by exploring all the paths from a given point to all the possible destinations.

http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf

Internet

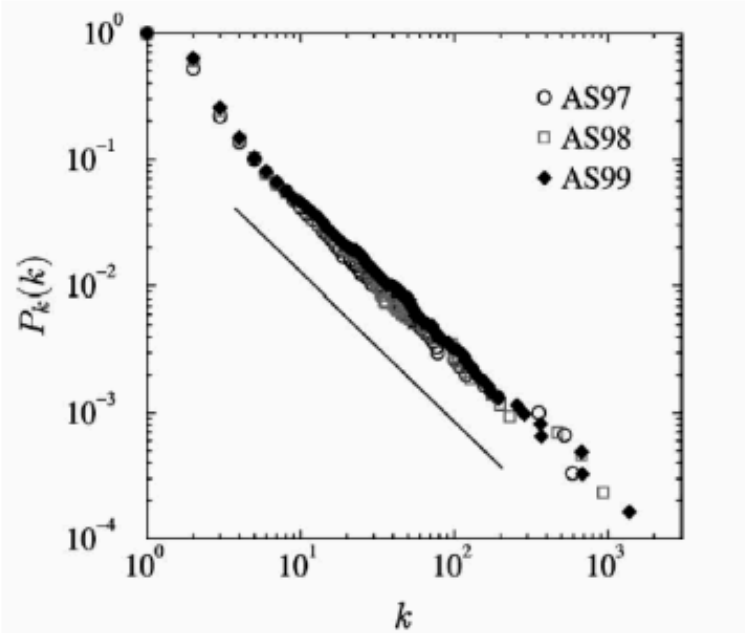


TABLE I. Total number of new (N_{new}) and deleted (N_{del}) nodes in the years 1997, 1998, and 1999. We also report the number of deleted nodes with connectivity $k>10$.

Year	1997	1998	1999
N_{new}	309	1990	3410
N_{del}	129	887	1713
$N_{del}(k>10)$	0	14	68

TABLE II. Average properties of the Internet for three different years. N, number of nodes; E, number of connections; $\langle k \rangle$, average connectivity; $\langle c \rangle$, average clustering coefficient; $\langle \ell \rangle$, average path length; $\langle b \rangle$, average betweenness. Figures in parentheses indicate the statistical uncertainty from averaging the values of the corresponding months in each year.

Year	1997	1998	1999
N	3112	3834	5287
E	5450	6990	10100
$\langle k \rangle$	3.5(1)	3.6(1)	3.8(1)
$\langle c \rangle$	0.18(3)	0.21(3)	0.24(3)
$\langle \ell \rangle$	3.8(1)	3.8(1)	3.7(1)
$\langle b \rangle / N$	2.4(1)	2.3(1)	2.2(1)

A. Vazquez, R. Pastor-Satorras and A. Vespignani PRE **65** 066130 (2002)

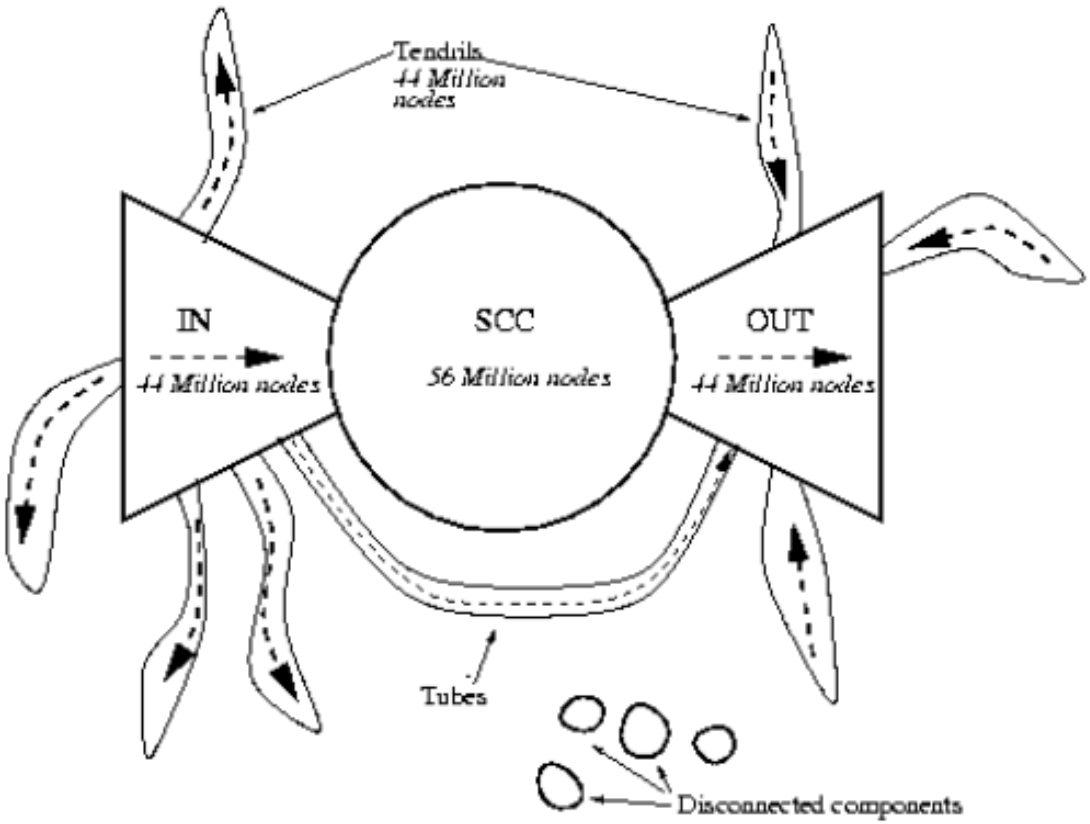
R. Pastor-Satorras and A. Vespignani *Evolution and Structure of Internet: A Statistical Physics Approach.* Cambridge University Press (2004)

http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf

Technological Networks

WORLD WIDE WEB

WWW (Bow-tie structure)



WWW is probably the largest network available of the order of billions of elements. Different centrality properties arise in such structure.

A. Broder et al. *Computer Network*, **33**, 309 (2000).

D. Donato et al. *Journal of Phys A*, **41**, 224017 (2008).

http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf

WWW (Bow-tie structure)

- The bow-tie picture of the Web provides a high-level view of the Web's structure
  - Based on its reachability properties and how its strongly connected components fit together
- We see that the Web contains a central "core" containing many of its most prominent pages, with many other nodes that lie upstream, downstream, or "off to the side" relative to this core

WWW (Bow-tie structure)

- It is also a highly dynamic picture: as people create pages and links, the constituent pieces of the bow-tie are constantly shifting their boundaries, with nodes entering (and also leaving) the giant SCC over time

Social Networks

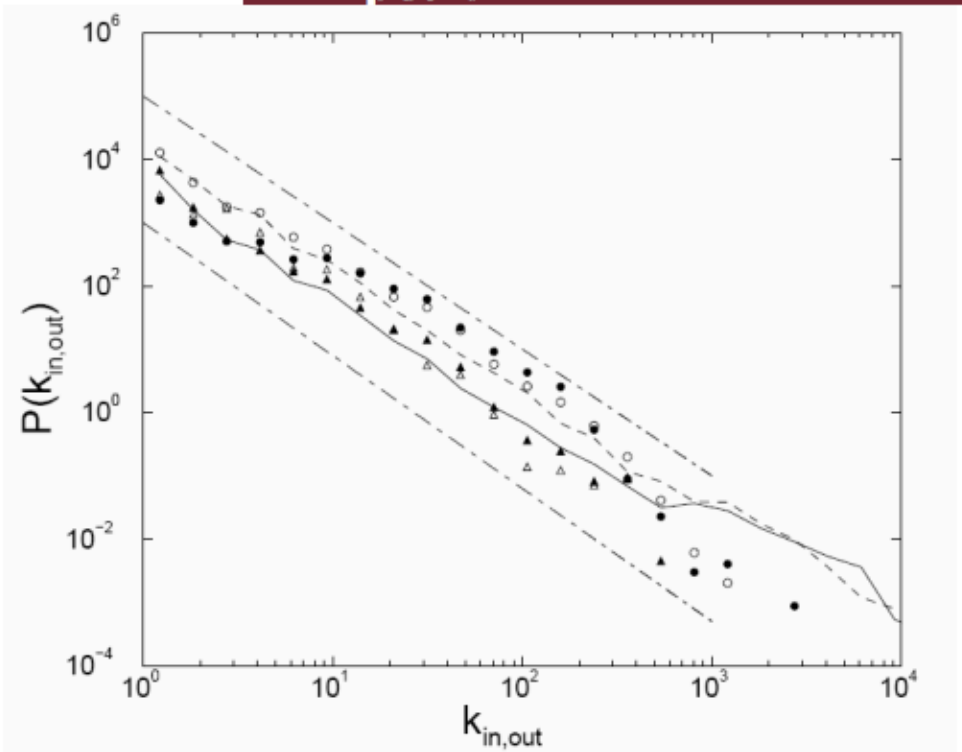
WIKIPEDIA

Wikipedia

http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf

Wikipedia

Wikipedia



in–degree(empty) and out–degree(filled) Occurrency distributions for the Wikgraph in English (o) and Portuguese (Δ).

The degree shows fat tails that can be approximated by a power-law function of the kind $P(k) \sim k^{-\gamma}$ Where the exponent is the same both for in-degree and out-degree.

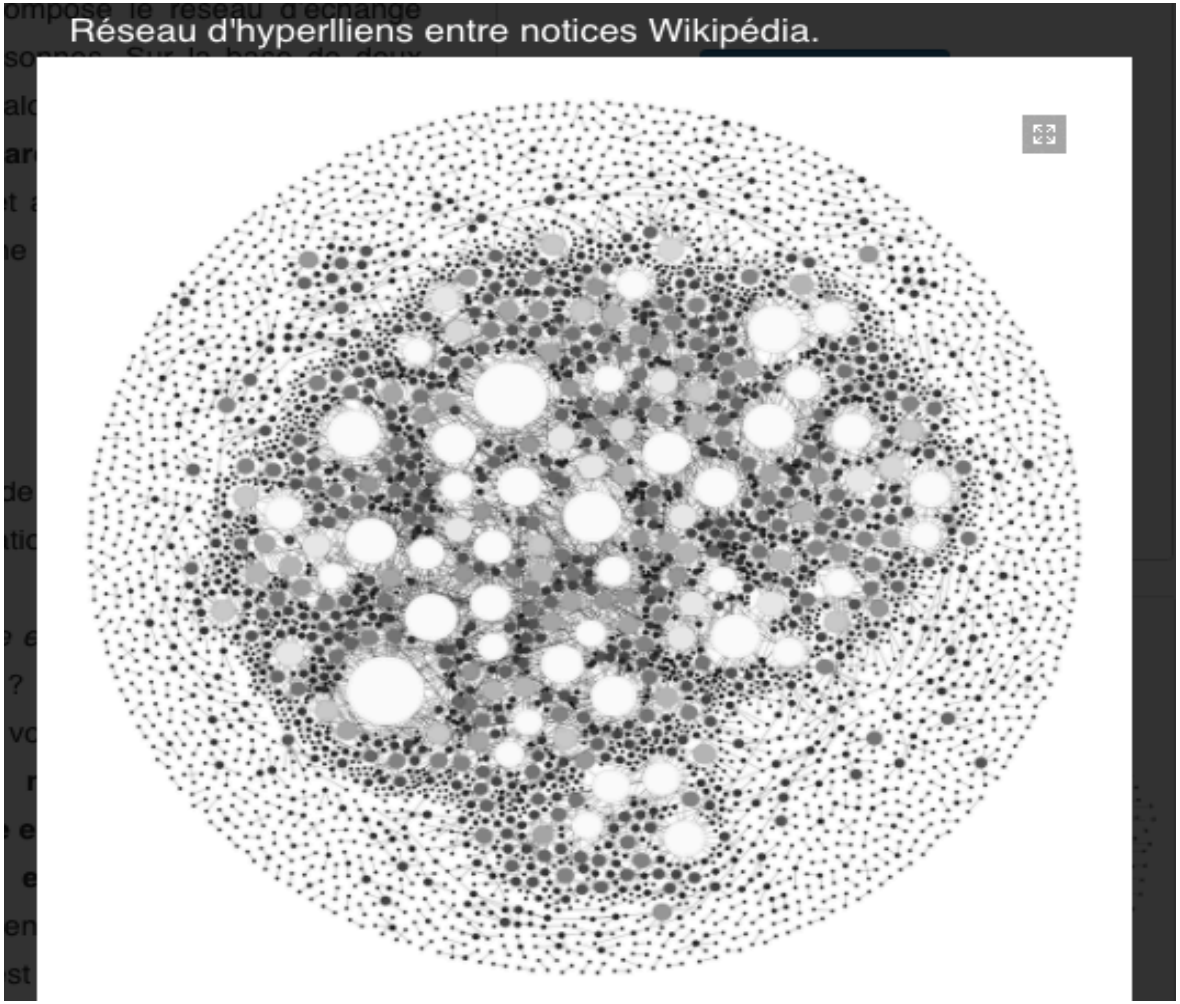
DB	|V|	|E|
PT	8,645	51,231
IT	13,132	159,965
ES	27,262	288,766
FR	42,987	660,401
DE	116,251	2,163,405
EN	339,834	5,278,037

V. Zlatic et al. *Physical Review E*, **74**, 016115 (2006).

A. Capocci et al. *Physical Review E*, **74**, 036116 (2006).

http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf

Wikipedia



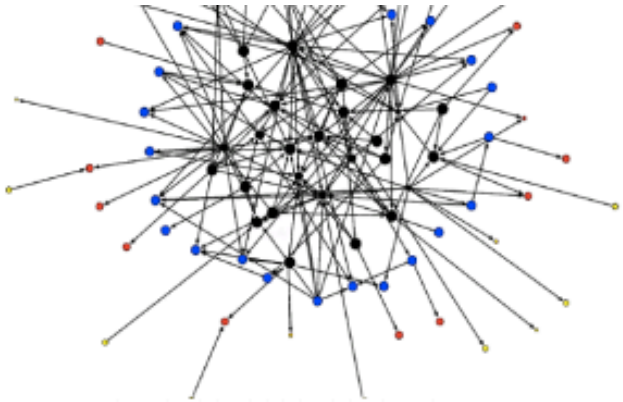
http://www.martingrandjean.ch/la-connaissance-est-un-reseau-perspective-sur-lorganisation-archivistique-et-encyclopedique/

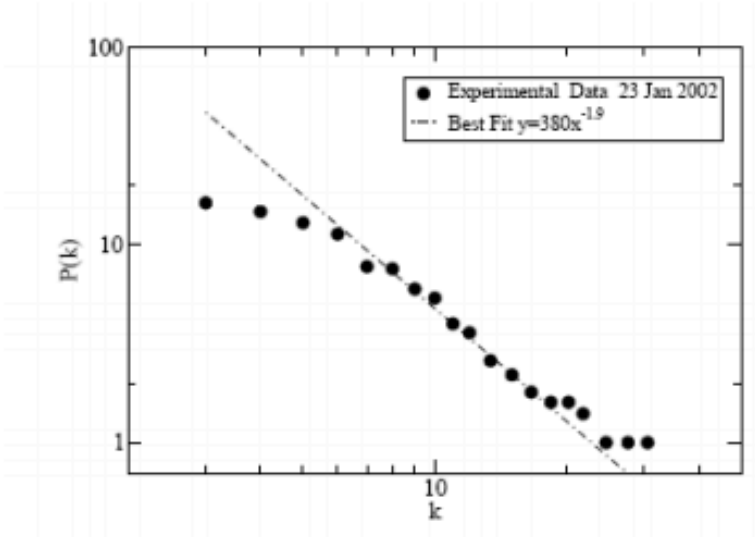
Financial Networks

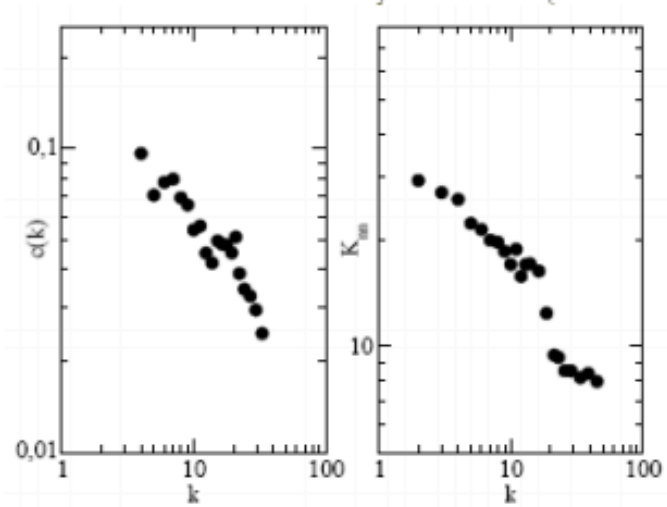
BANK’S CREDIT NETWORK

Bank's credit network

Banks exchange money overnightly, in order to meet the customer needs of liquidity as well as ECB requirements







The network shows a rather peculiar architecture

The banks form a disassortative network where large banks interact mostly with small ones.

http://www.ifr.ac.uk/netsci08/Download/Invited/ws1_Caldarelli.pdf

IMPACT OF STUDYING COMPLEX NETWORKS

Economic: From web search to social networking

- Some of the most successful companies of the 21st century base their technology and business model on networks
  - Google to Facebook, Cisco to Apple
- Network popularity: Facebook
- Tools from network science: aid from friend recommendation to advertising

Economic: From web search to social networking

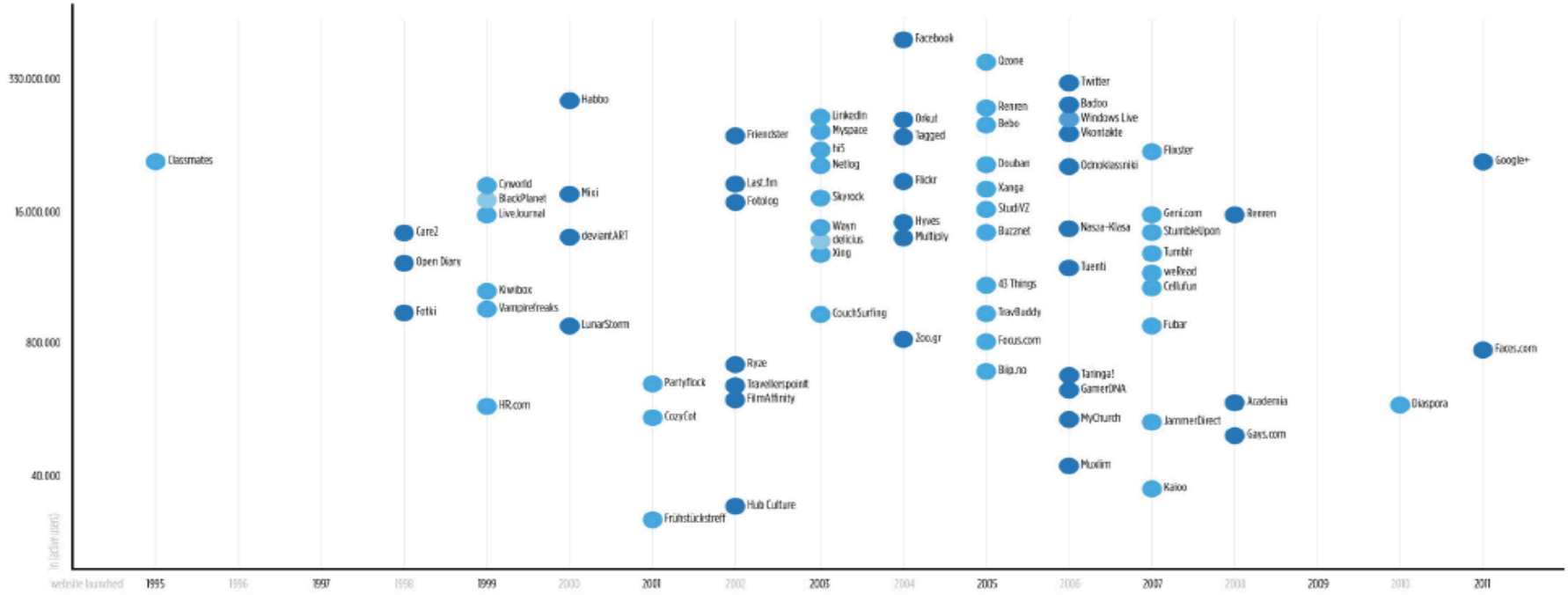


Image 1.6
The rise of social networking.

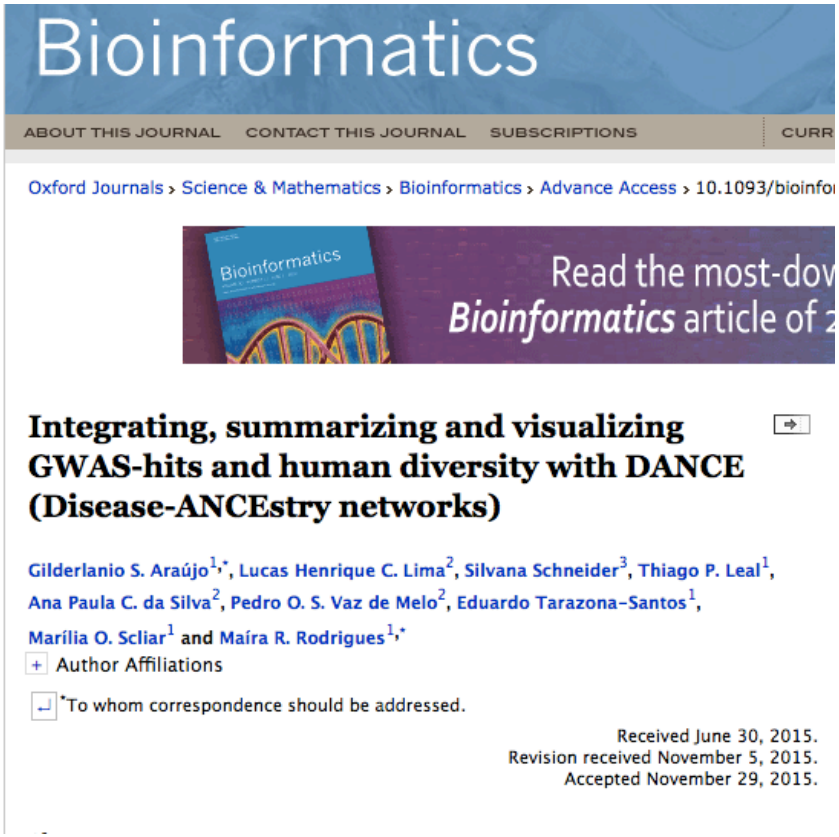
The popularity of the best known social networks, in terms of the number of users they attracted by the end of 2011 (vertical axis) shown as a function of their founding year (horizontal axis).

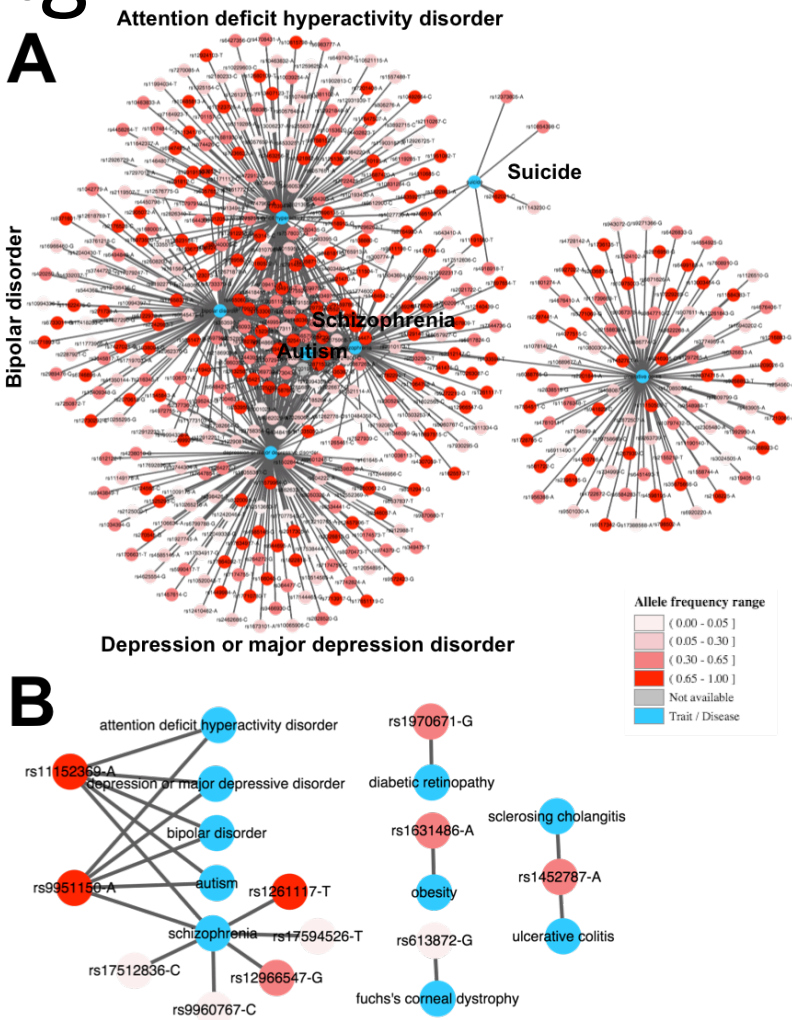
Network Science Book – Albert Barabasi

Health: From drug design to metabolic engineering

- Accurate maps that tell how genes and other cellular components interact with each other allows us to understand how our cells function and the origin of several diseases
- Network medicine: uncover the role of networks in human disease

Health: From drug design to metabolic engineering





A: SNP-Disease Network for bipolar disorder and neighboring phenotypes. B: TCF4 gene-diseases network. SNPs are colored according to risk-allele frequency in Africans (A) and Asians (B).

Epidemics: From forecasting to halting deadly viruses

- H1N1 was the first pandemic whose course and time evolution was accurately predicted months before the pandemic reached its peak
- Possible thanks to fundamental advances in understanding the role of networks in the spread of viruses.
- Emergence of a network-based framework offered a new level of predictability in epidemic phenomena.

Epidemics: From forecasting to halting deadly viruses

Image 1.9
Predicting the H1N1 epidemic.

The predicted spread of the H1N1 epidemics during 2009, representing the first successful prediction of a pandemic. The project, relying on the details of the worldwide transportation networks, foresee that H1N1 will peak out in October 2009, in contrast with the normal January–February peaks of influenza. This meant that the vaccines planned for November 2009 were too late, which was indeed the case. The success of this project shows the power of network science in facilitating advances in areas affected by networks.

Movie by D.Balcom, B.Gonçalves, H.Hu, and A.Vespignani.

Network Science Book – Albert Barabasi

Epidemics: From forecasting to halting deadly viruses

- Epidemic prediction is one of the most active applications of network science.
- Impact of these advances are felt beyond biological viruses
  - 2010 network science tools have predicted the conditions necessary for the emergence of viruses spreading through mobile phones
  - First major mobile epidemic outbreak in China (fall of 2010) , closely followed the predicted scenario (over 300,000 phones each day)

Brain Research: Mapping neural network

- Is the one of the least understood networks from the perspective of network science: lack maps of how neurons link to each other.
- In 2010 the National Institutes of Health has initiated the Connectome project, aimed at developing the technologies that could provide an accurate neuron-level map of mammalian brains.

Management: Uncovering the internal structure of an organization

- Network capturing who really communicates with whom, matters even more for the success of a company. Accurate maps of this network can:
  - Expose lack of communication between key units;
  - Identify individuals who play an outsize role in bringing different departments and products together;
  - Help higher management diagnose diverse organization issues.

- There is increasing evidence in the management literature that the position of an employee within this network correlates with his/her productivity.

Management: Uncovering the internal structure of an organization

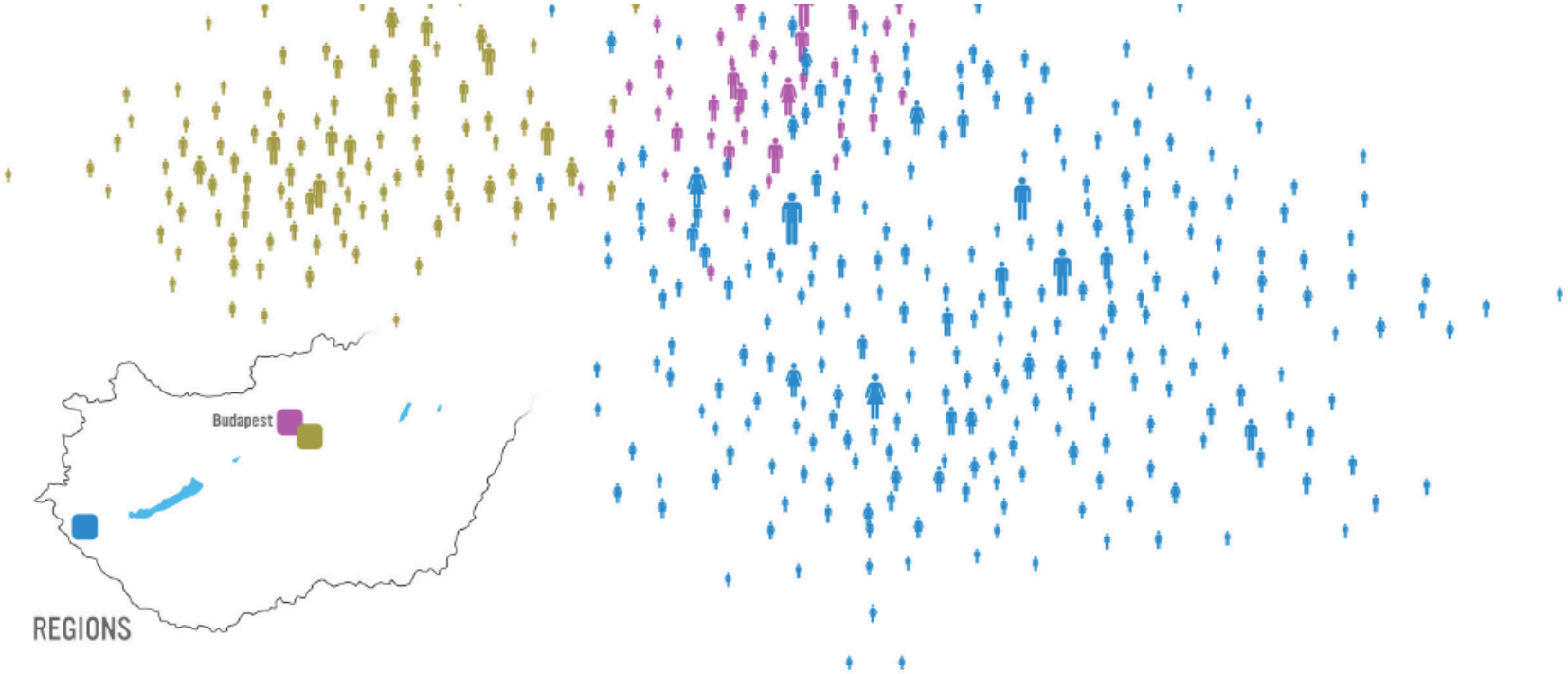


Image 1.10a

Understanding the inner workings of an organization.

The workforce of a Hungarian company with three main locations, one on Budapest, whose employees are shown in purple, and two manufacturing sites outside of the city, shown in yellow and blue. The company had a major internal communication problem: information that reached the workers about the intentions of the higher management often had nothing do to with the management's real plans. Seeking to understand the source of this discrepancy, and looking for ways to embrace information flow within the company, the management turned to Maven 7, a social networking consulting company that applies network science in diverse organizational setting.

Network Science Book – Albert Barabasi

Management: Uncovering the internal structure of an organization

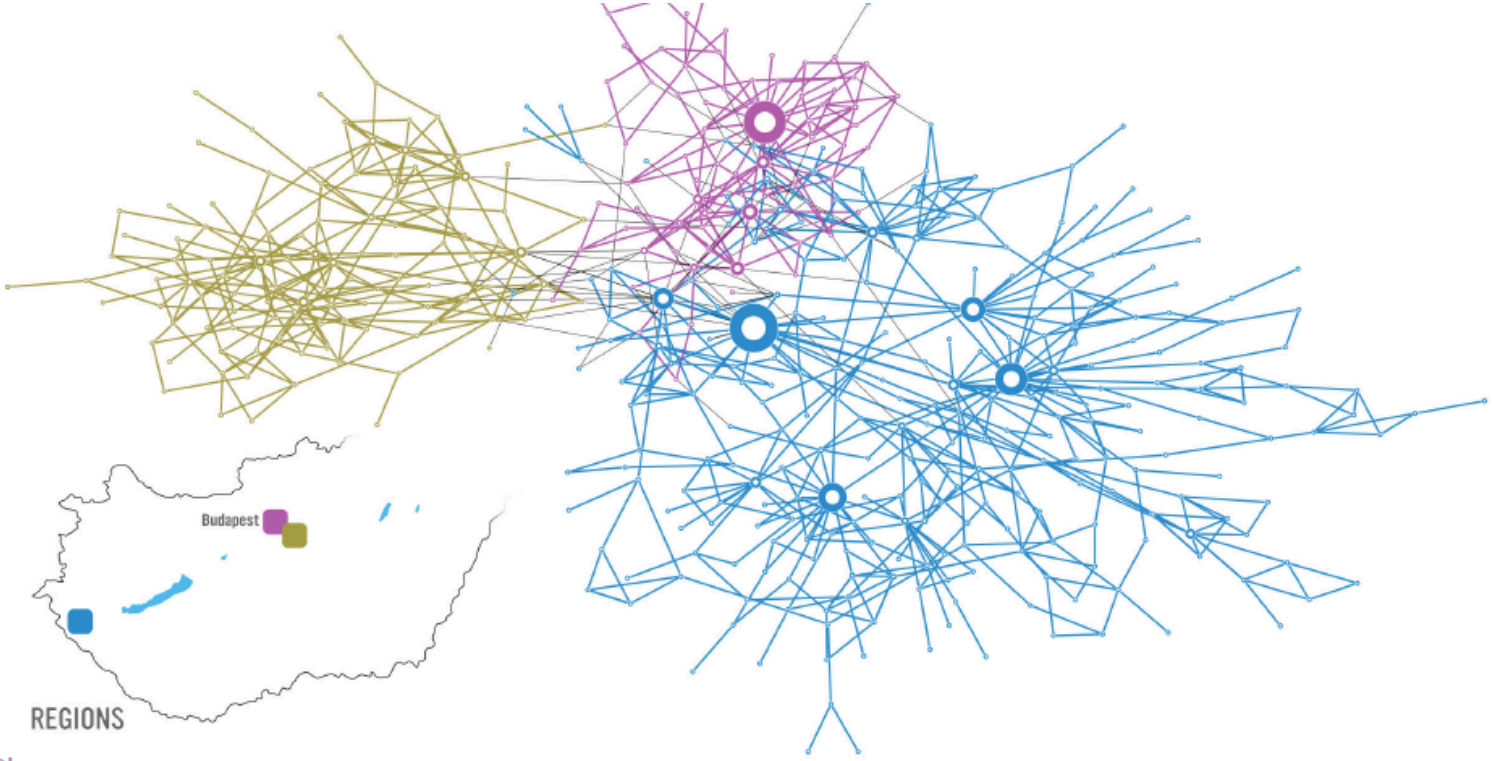


Image 1.10b

Understanding the inner workings of an organization.

Having the list of the workers and their role in the company, together with the official hierarchy is not sufficient to understand how an organization works. For that we need to know who listens to whom, who is asking for advice from whom, eventually uncovering the paths through which knowledge and information travels within the organization. Hence Maven 7 developed an online platform to ask each employee whom do they turn to for advice when it comes to decisions impacting the company, from restructuring to advancement. This allowed them to build the map shown above, where two individuals are connected if one nominated the other as his/her source of information on organizational and professional issues.
The map identifies several highly influential individuals that are the hubs of the organization. The problem was that none of the hubs were part of the leadership.

Network Science Book – Albert Barabasi

Management: Uncovering the internal structure of an organization

Image 1.10c

Understanding the inner workings of an organization.

The position of the leadership within the company's informal network is illustrated on this map, where we colored the nodes based on their company rank within the company. None of the company directors, including the CEO, shown in red, are hubs. Nor are the top managers, shown in blue. The hubs are managers, group leaders and associates, or workers. The biggest hub, hence the most influential individual, is an associate, shown as a gray node in the center.

Network Science Book – Albert Barabasi

Management: Uncovering the internal structure of an organization

Image 1.10d

Understanding the inner workings of an organization.

The image indicates that a significant fraction of employees are one to two links from the biggest hub. It turns out that he is the safety and environmental expert in the company, whose job is to visit each location and talk with most employees. There is only one part of the company he has no links to: the directors or the top management. With little access to the management and their intentions, he passes on information that he collects along his trail, effectively running a gossip center.

Network Science Book – Albert Barabasi

Management: Uncovering the internal structure of an organization

How does one remedy this situation? Fire the biggest hub? He is not the problem and firing him would probably make the problem even more acute. The real issue is that higher management failed to put in place proper channels of communication, leaving behind a structural hole, which was naturally filled by the environmental and safety manager. Offering him and the few other hubs access to the true information can fundamentally change the reliability of information within the company. Network science can therefore offer a potent microscope for higher management, helping them improve the company's effectiveness by uncovering the true network behind an organization.

Network Science Book – Albert Barabasi

About our Course

Goals

1) Introduce basic concepts in complex network (network science)

2) Discuss metrics and models

3) Use software analysis tools to experiment with a wide variety of real-world network data.

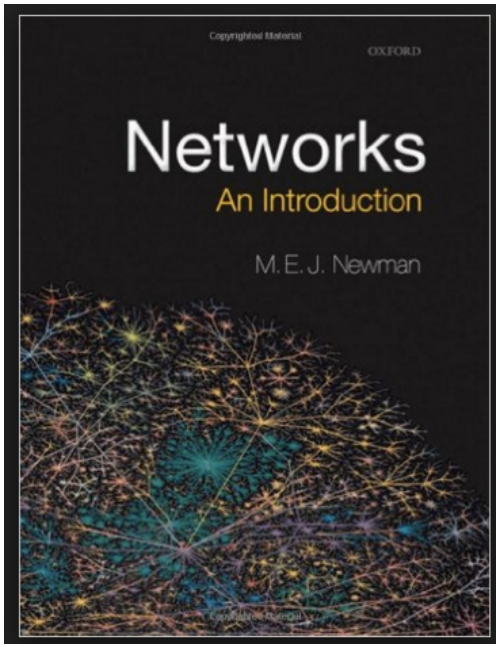
Syllabus

- Introduction to Networks: the role of networks in life, nature, and research. Model networks: structure & dynamics
- Basic Network Concepts: network definition and its characteristics
- Network Centrality: node degree, closeness, betweenness, eigenvector (page rank)
- Small-world Networks: Milgram´s small world experiment, small world network models
- Power-laws "Scale free" networks: Barabasi-Albert model
- The structure of the Web and Link analysis
- Strong and weak ties: triadic closure, the strength of weak ties, tie strength and network structure in large-scale data. Tie Strength, Social Media, and Passive Engagement. Closure, Structural Holes, and Social Capital
- Networks in their surrounding contexts: homophily, selection and social influence, affiliation
- Information cascades: following the crowd
- Cascade Behavior in Networks: diffusion in networks. Modeling diffusion through a network, diffusion. Thresholds, and the Role of weak ties.
- Epidemiological models: Branching processes, SIR Model, SIS Model, Synchronization, Transient contacts and the dangers of concurrency
- Software Analysis tools: NetLogo

Grading Policy

- 2 Exams: 25 points each
- Homework: 20 points
- Research Project: 30 points

Some books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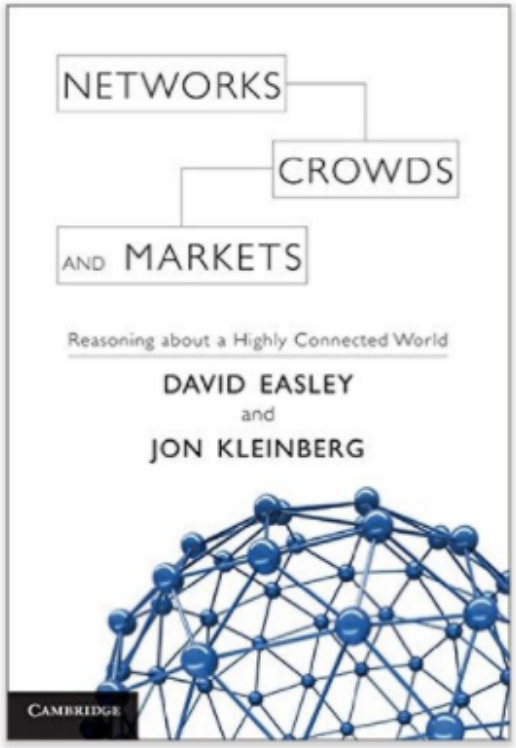
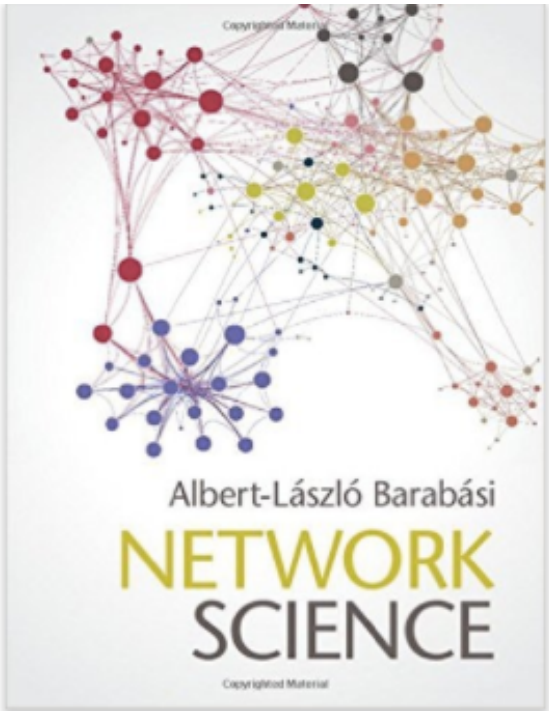
OXFORD
Networks
An Introduction
M. E. J. Newman


NETWORKS
CROWDS
AND MARKETS
Reasoning about a Highly Connected World
DAVID EASLEY
and
JON KLEINBERG
CAMBRIDGE


Albert-László Barabási
NETWORK
SCIENCE
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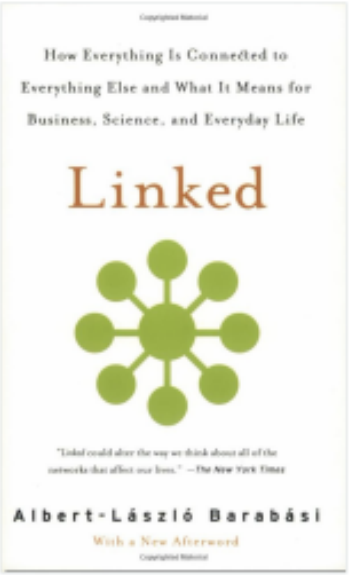
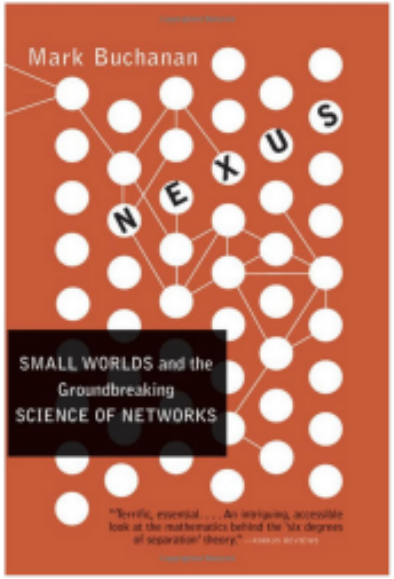
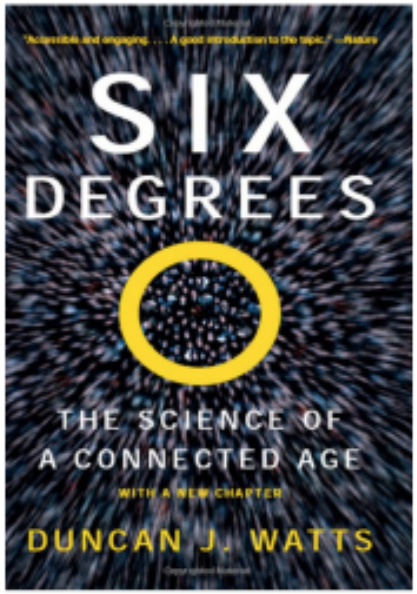
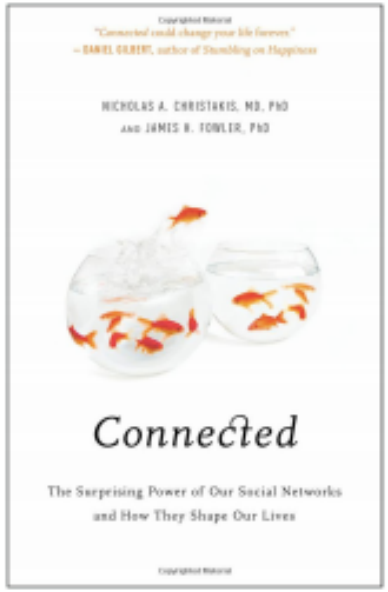
Some books


How Everything Is Connected to Everything Else and What It Means for Business, Science, and Everyday Life
Linked
Albert-László Barabási
With a New Afterword


Mark Buchanan
NEXUS
SMALL WORLDS and the Groundbreaking SCIENCE OF NETWORKS

The Hidden Pattern Behind Everything We Do
BURSTS
Albert-László Barabási
Author of LINKED


SIX DEGREES
THE SCIENCE OF A CONNECTED AGE
WITH A NEW CHAPTER
DUNCAN J. WATTS


NICHOLAS A. CHRISTAKIS, MD, PhD
AND JAMES H. FOWLER, PhD
Connected
The Surprising Power of Our Social Networks and How They Shape Our Lives

Some interesting references

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3. D. J. Watts and S .H. Strogatz. *Collective dynamics of 'small-world' networks*. Nature, 393 (440), 1998.
4. A.-L. Barabási and R. Albert. *Emergence of scaling in random networks*, Science, 286 (509), 1999
5. P. Erdős and A. Rényi. *On random graphs*. Publicationes Mathematicae, 6 (290), 1959.
6. M. S. Granovetter. *The strength of weak ties.* American Journal of Sociology, 78 (1360), 1973.
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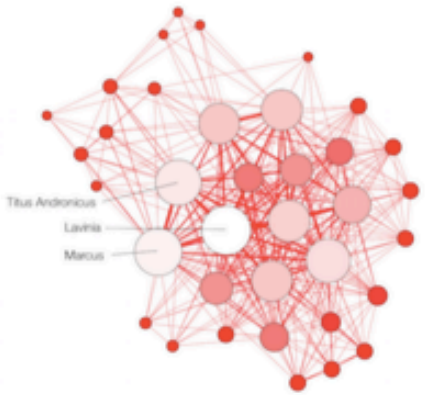
Shakespeare tragedies mapped out with network visualizations

- Every story has its architecture, its joints and crossbeams, ornaments and deep structure
- The boundaries and scope of a story, its built environment, can determine the kind of story it is: tragedy, comedy, or otherwise
- Every story also, it appears, generates a network: a web of weak and strong connections, hubs and nodes

http://www.martingrandjean.ch/network-visualization-shakespeare/

SHAKESPEAREAN TRAGEDY

(The 11 tragedies in chronological order)



TITUS ANDRONICUS

Number of characters 36 | 50% Network density

ROMEO AND JULIET

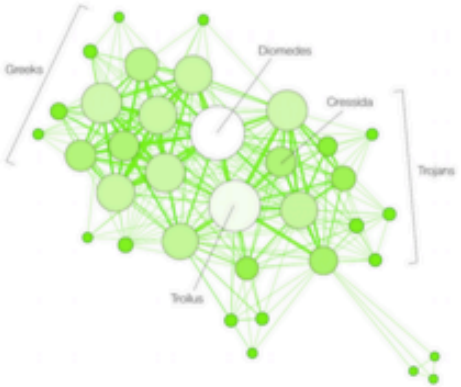
Number of characters 41 | 37% Network density

JULIUS CAESAR

Number of characters 46 | 34% Network density

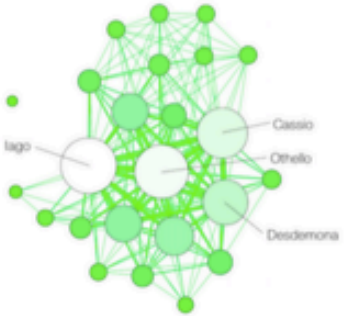
HAMLET

Number of characters 37 | 39% Network density



TROILUS AND CRESSIDA

Number of characters 35 | 40% Network density



OTHELLO

Number of characters 24 | 55% Network density

KING LEAR

Number of characters 33 | 45% Network density

MACBETH

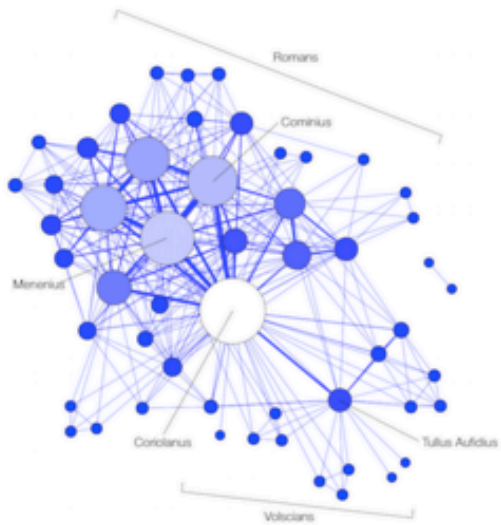
Number of characters 46 | 25% Network density

TIMON OF ATHENS

Number of characters 51 | 25% Network density

ANTONY AND CLEOPATRA

Number of characters 74 | 17% Network density



CORIOLANUS

Number of characters 53 | 21% Network density

ABOUT

Two characters are connected if they appear in the same scene.
Their size and color intensity are proportional to their weighted degree.
The 'network density' measures how close the graph is to complete. A complete graph (100%) has all possible edges between its nodes.

Shakespeare tragedies mapped out with network visualizations

- Hamlet is not the most structurally complex and is less dense than King Lear, Titus Andronicus or Othello
- Some plays reveal clearly the groups that shape the drama: Montague and Capulets in Romeo and Juliet, Trojans and Greeks in Troilus and Cressida

http://www.martingrandjean.ch/network-visualization-shakespeare/

And more …

- http://www.martingrandjean.ch/metro-quiz-15-subway-networks/
- http://www.martingrandjean.ch/invisible-analyse-de-reseau-journalisme-investigation/

And more …

***Character networks in Jean-Jacques Rousseau's* Confessions**

We sketch a theoretical framework for literary network analysis, bringing together narratology, distant reading and social network analysis. We extract co-occurrences from a book index without the need for text analysis and describe the narrative roles of the characters. As a case study, we use the autobiographical novel Les Confessions from Jean-Jacques Rousseau. Eventually, we compute four types of centrality — degree, closeness, betweenness, eigenvector — and use these measures to propose a typology of narrative roles for the characters.