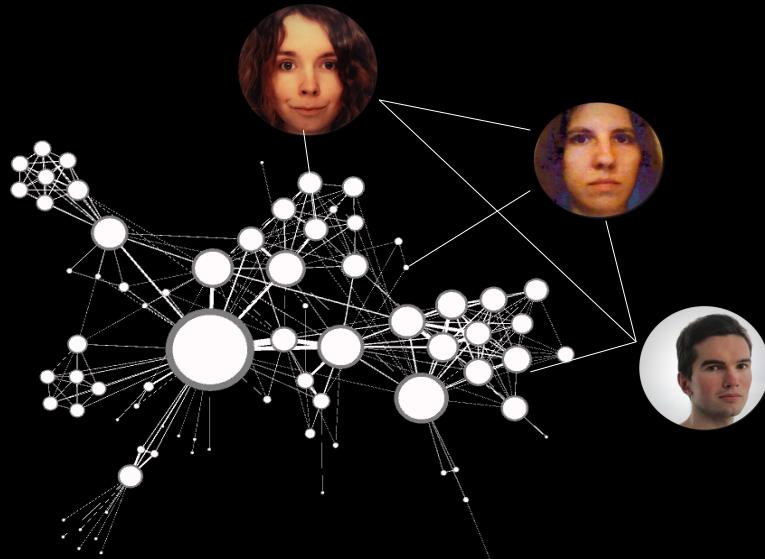




Network theory: 1 introduction to networks theory and complex systems

Liubov Tupikina (CRI)

WHO am I?



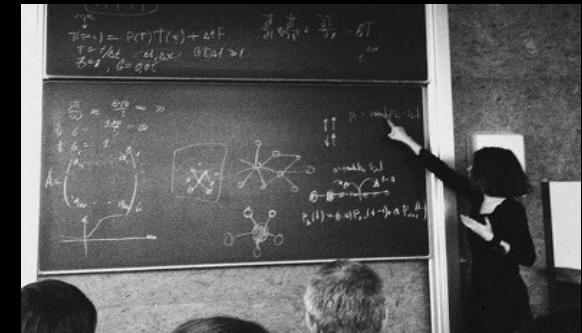
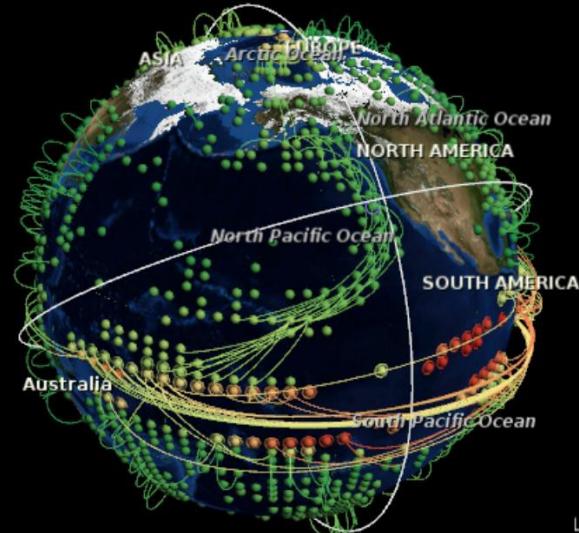
liubov tupikina (CRI, France)
liubov.tupikina@cri-paris.org

networks, spreading, data analysis
connections between people

Donges, Heitzig, LT, Kurths et al., Chaos (2015)

LT, Molkenthin, Hernandez-Garcia, et.al, PlosOne (2016)

<https://research.cri-paris.org/ocean-health/analyzing-heterogeneous-spreading-dynamics/lecturers-without-border-scied.network>



Phd in theoretical physics
Applied maths, data analysis,
biophysics projects (HU, UU,
X, Tech, MIPT...)



Marc Santolini
Emma, Phd students of Marc

Structure of the course

Lecture 1: INTRODUCTION: network and graph theory + **first data hands-on**

Lecture 2: Network theory and methods for network analysis + **second data hands-on**

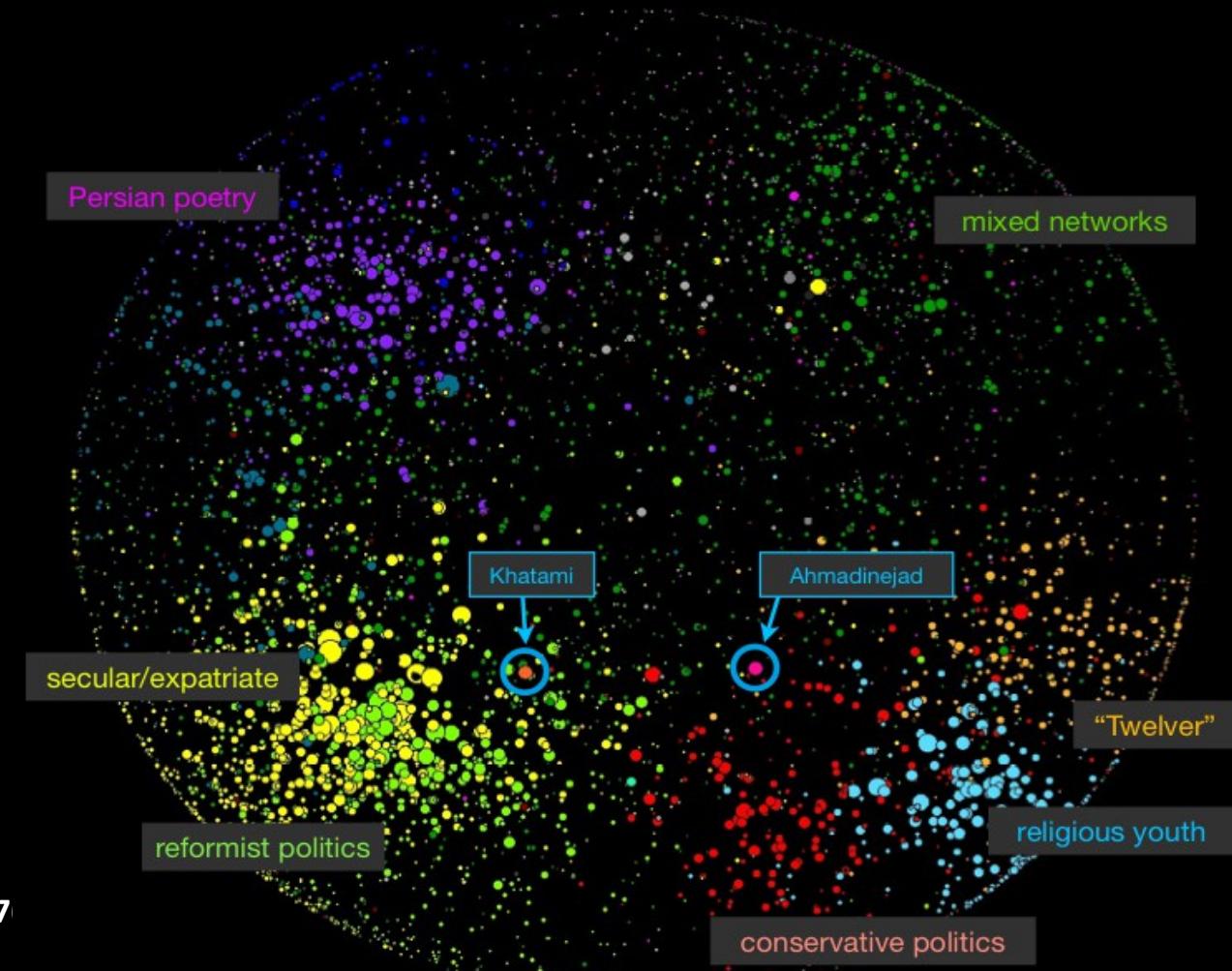
Lecture 3: Network theory and real world problems + **network quiz**

Different sides of network science:

Network data analysis

Network theory

Network visualizations



<https://journals.sagepub.com/doi/full/10.1177/2056305117>

Literature overview

<http://networksciencebook.com/>

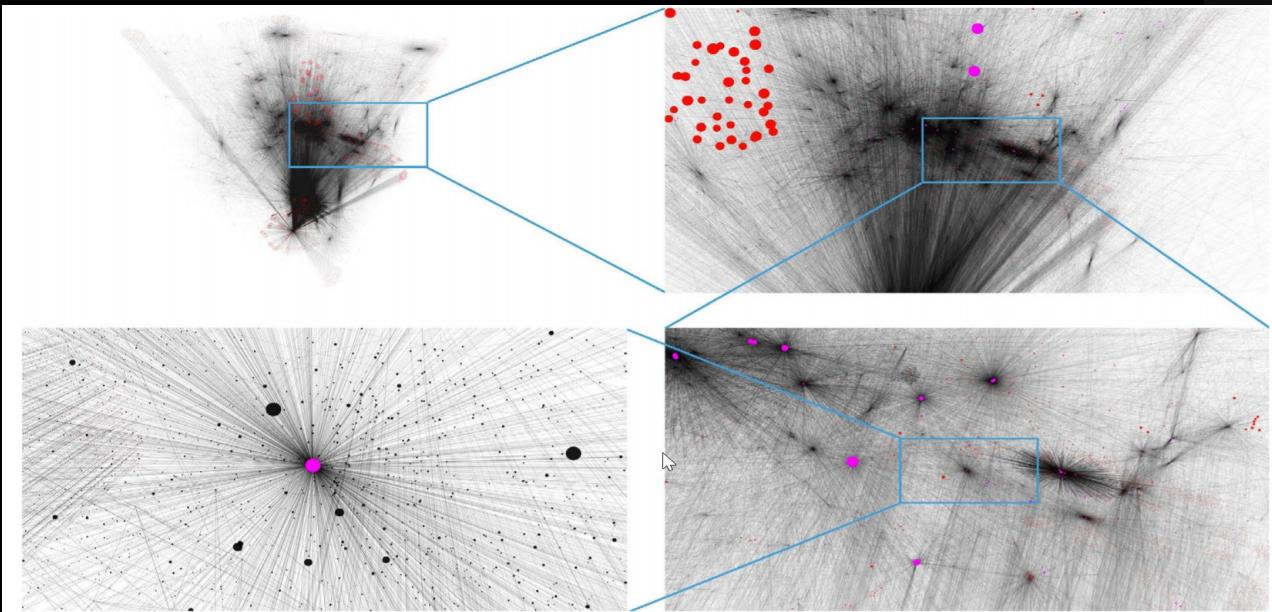
<https://www.barabasilab.com>

<http://networkrepository.com/graph-vis.php>

<http://www.complexity-explorables.org/explorables/neighbors/>

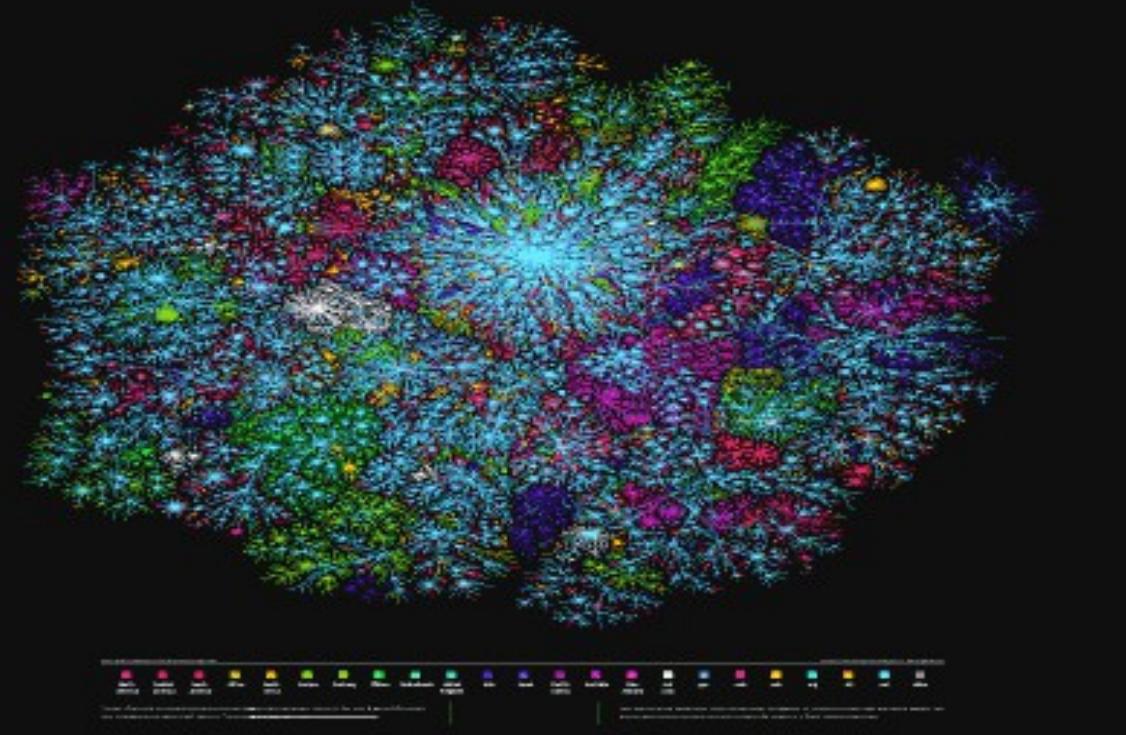
Spectral methods for complex systems online lectures

<https://sites.google.com/view/cssm/online-courses?authuser=0>



<https://sites.google.com/a/binghamton.edu/netscied/teaching-learning/network-concepts>

THE WHOLE INTERNET



<https://snap.stanford.edu/data>

Can you give examples of networks?

Networks at the heart of complex systems

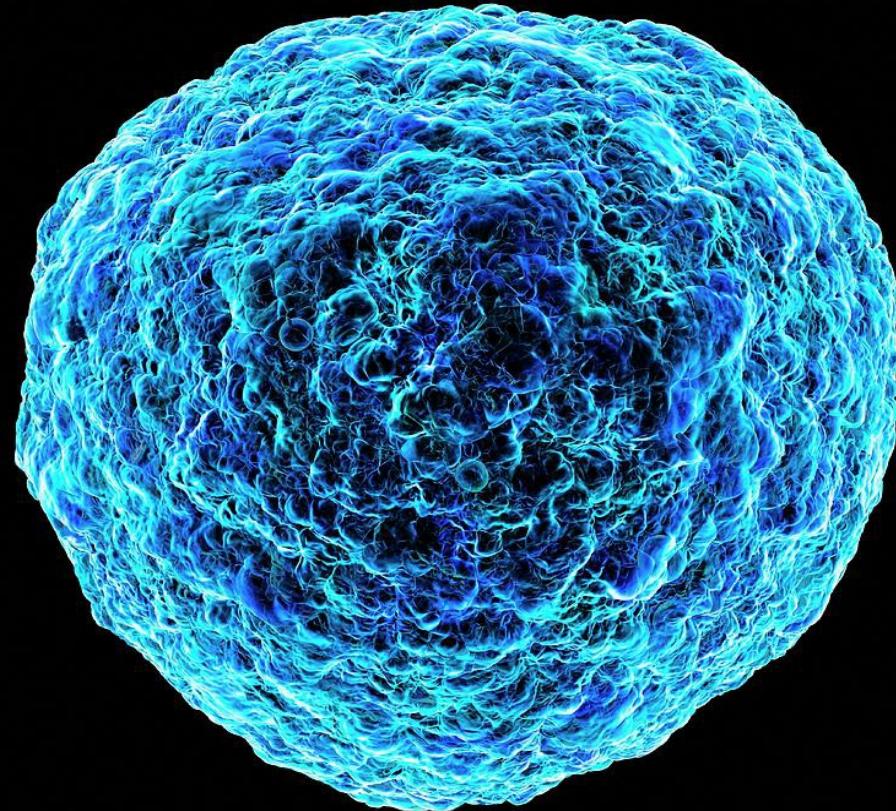
Can you give examples of networks?



Networks at the heart of complex systems

Can you give examples of networks?

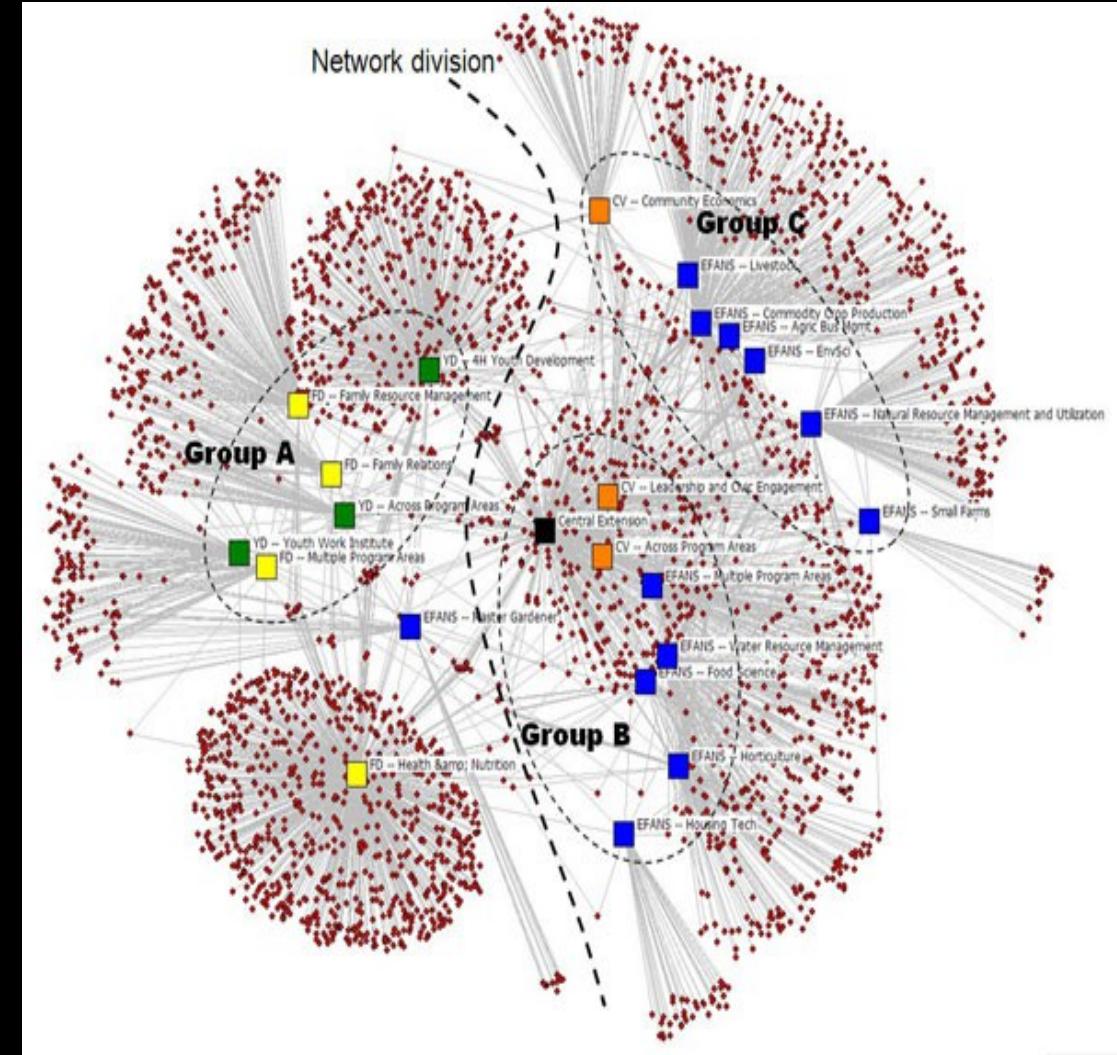
fineartamerica.com Human T-cell Leukemia Virus



Networks at the heart of complex systems

What is the complex system?

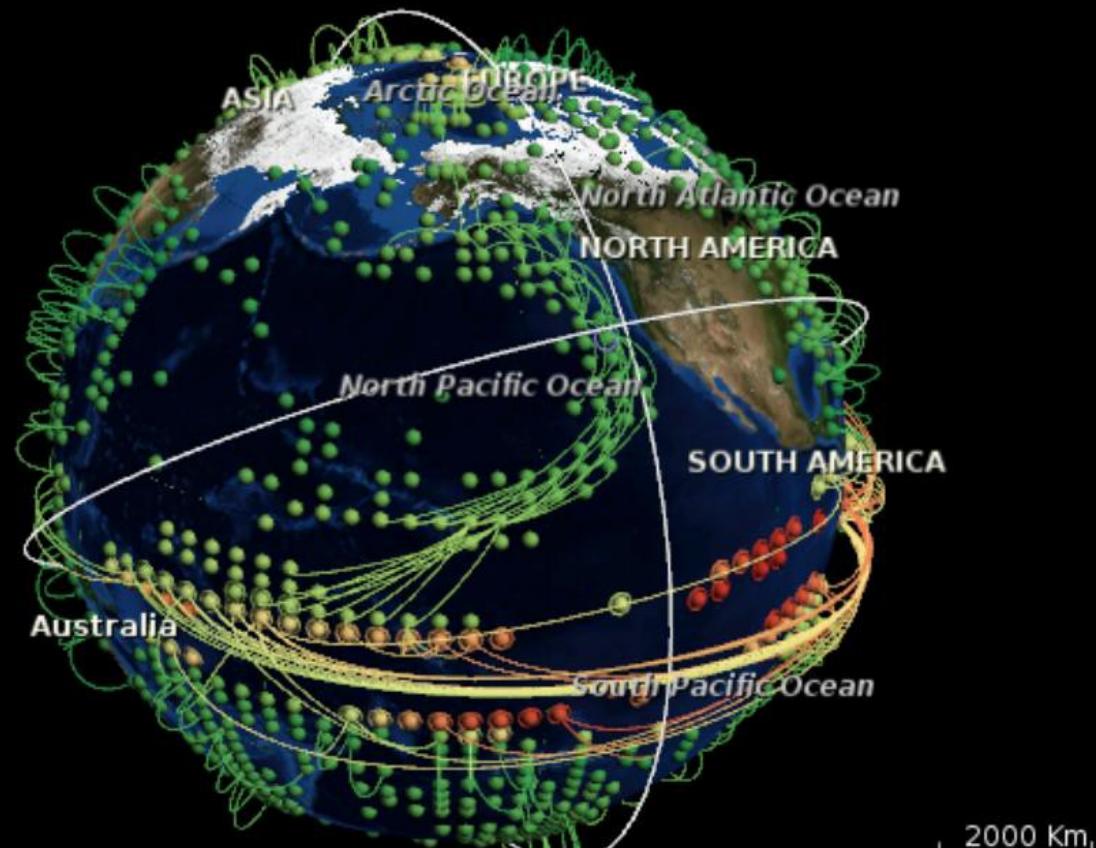
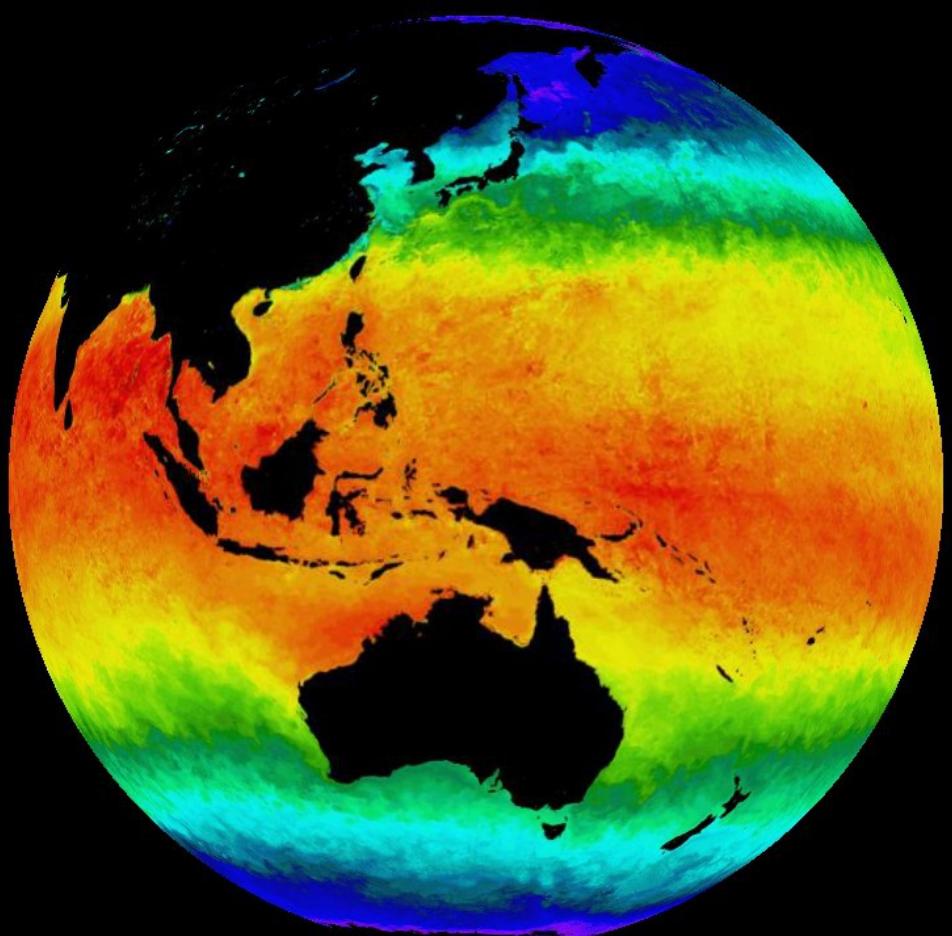
fineartamerica.com Human T-cell Leukemia Virus



Questions:

How to describe complex system?

What is the meaning of correlations patterns in data structures?



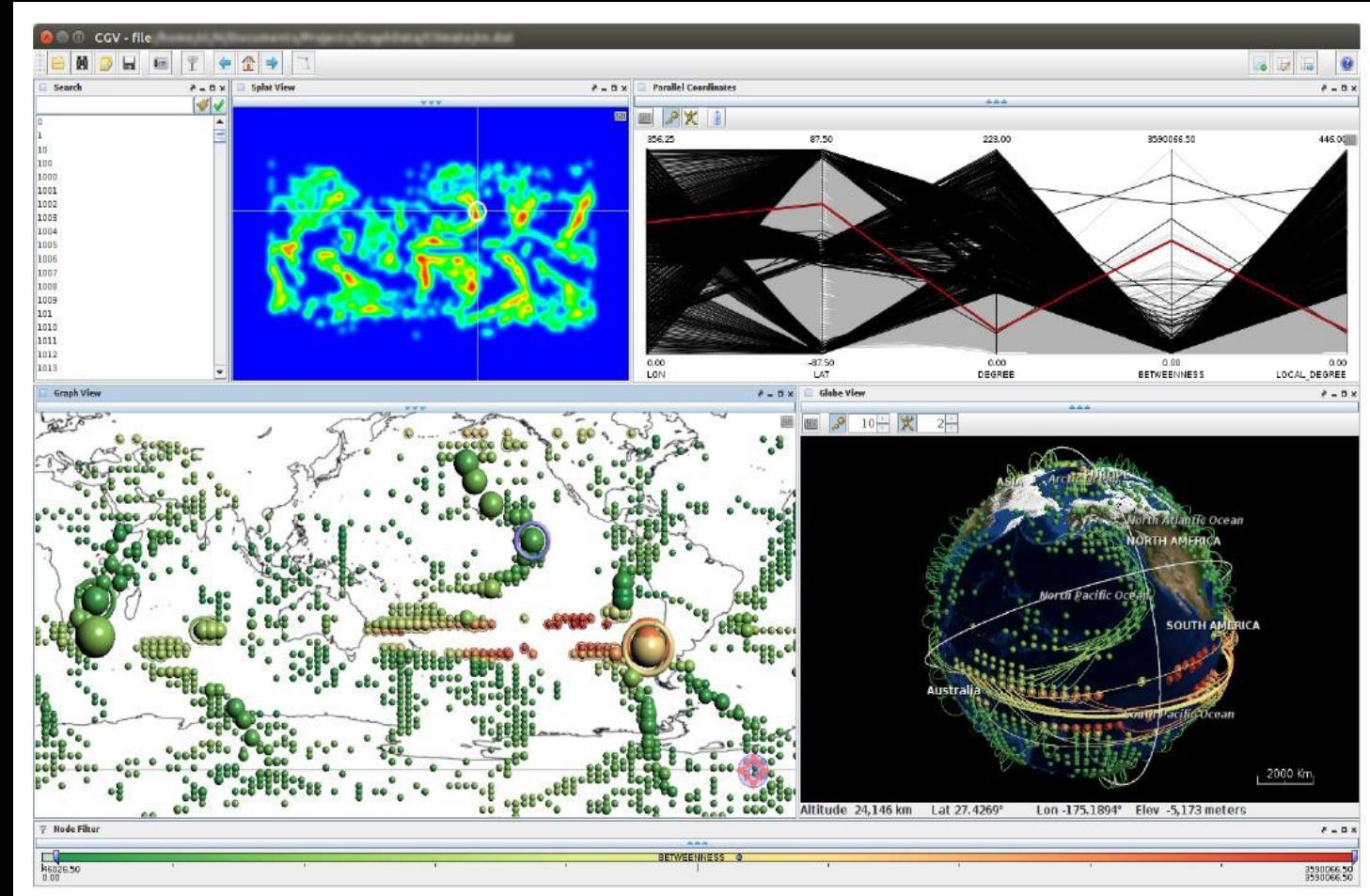
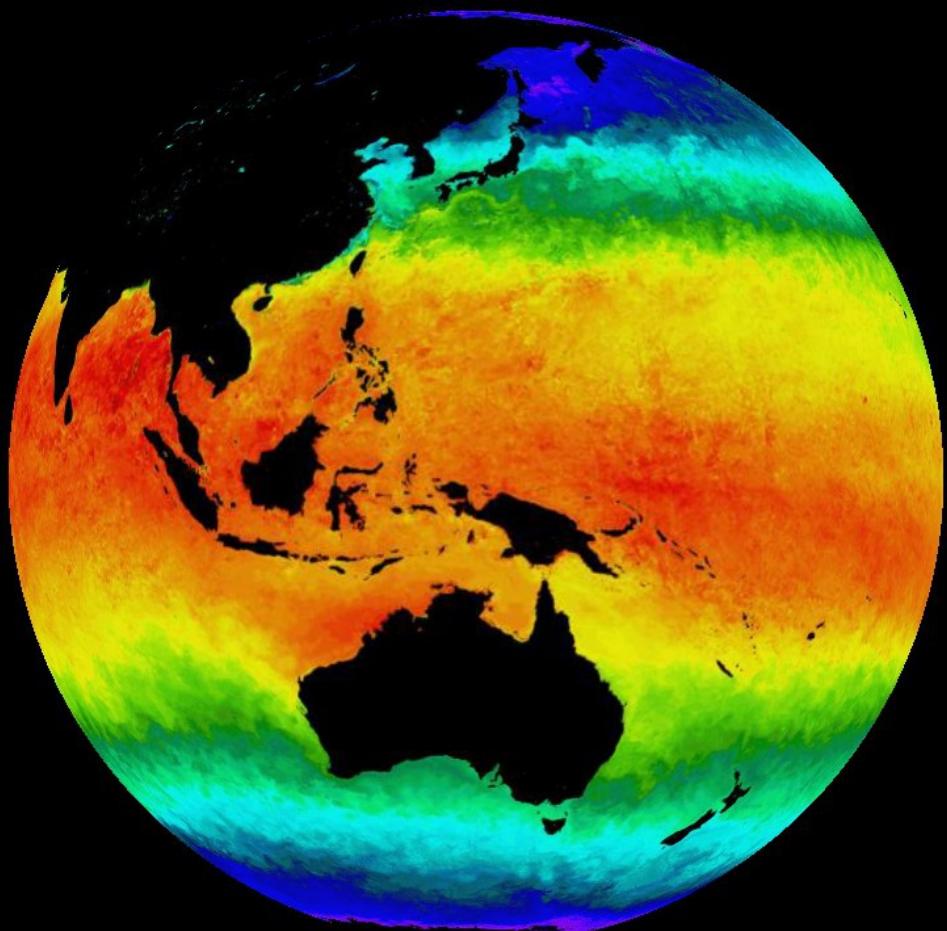
L.T. et al. "Characterizing the evolution of climate networks", Nonlin.
Processes Geophys., 21, 705-711 (2014)

J.F. Donges et al. "Unified functional network and nonlinear time series
analysis for complex systems science(...)", Chaos 25, 113101-1-25 (2015)
<http://www.pik-potsdam.de/~donges/pyunicorn/>

Questions:

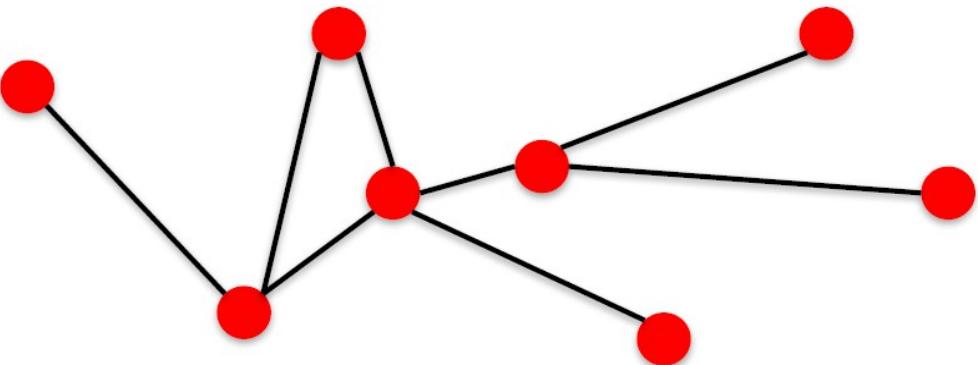
How to describe complex system?

What is the meaning of correlations patterns in data structures?



How to describe a network?

What is the network itself?



▪ **components**: nodes, vertices

N

▪ **interactions**: links, edges

L

▪ **system**: network, graph

(N,L)

If you
want to
know more ..

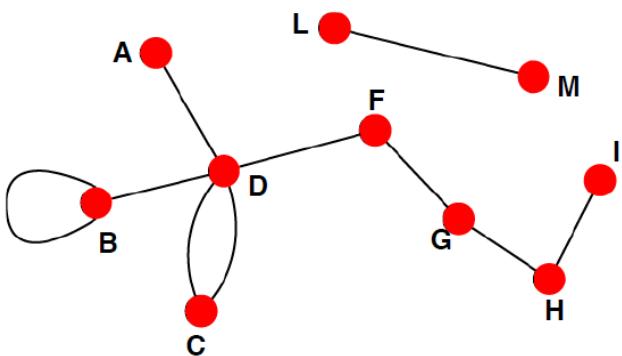


What is the network itself?

Undirected

Links: undirected (*symmetrical*)

Graph:



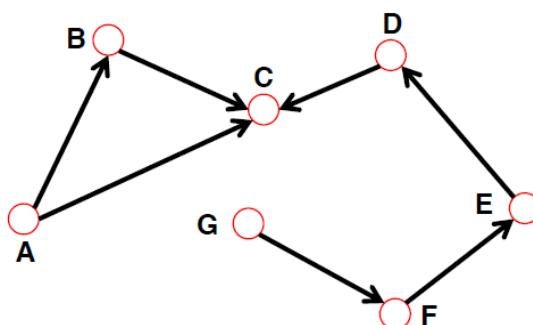
Undirected links :

coauthorship links
Actor network
protein interactions

Directed

Links: directed (*arcs*).

Digraph = directed graph:



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

If you want to know more ..

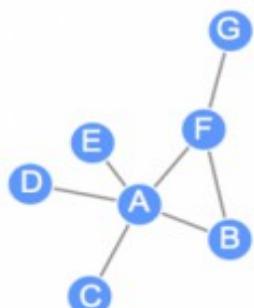
Directed links :

URLs on the www
phone calls
metabolic reactions

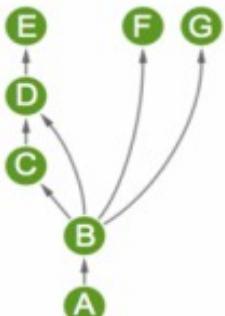
Barabasi book on network science

How to describe a network?

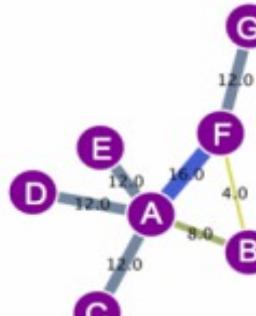
Undirected



Directed



Weighted



	A	B	C	D	E	F	G	Degree
A	0	1	1	1	1	1	0	5
B	1	0	0	0	0	1	0	2
C	1	0	0	0	0	0	0	1
D	1	0	0	0	0	0	0	1
E	1	0	0	0	0	0	0	1
F	1	1	0	0	0	0	1	3
G	0	0	0	0	0	1	0	1

Adjacency matrices

	A	B	C	D	E	F	G	Out-degree
A	0	1	0	0	0	0	0	1
B	0	0	1	1	0	1	1	4
C	0	0	0	1	0	0	0	1
D	0	0	0	0	1	0	0	1
E	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0
G	0	0	0	0	0	0	0	0

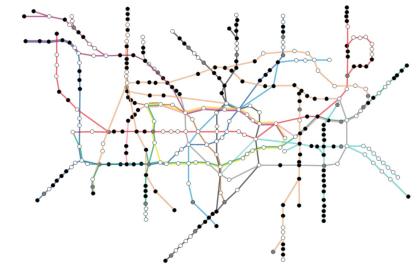


Barabasi book on network science

Question:

**How much information can you store in adjacency matrix?
What can you describe with it?**

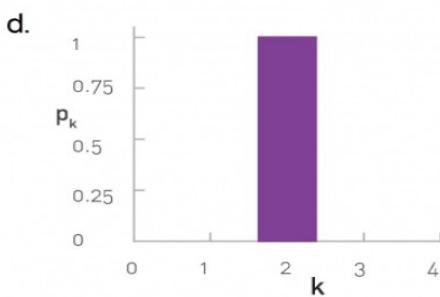
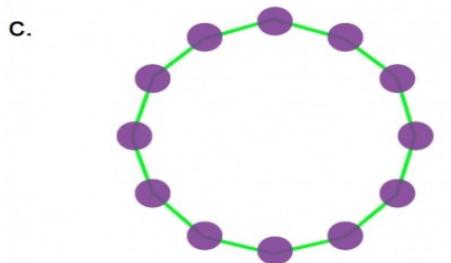
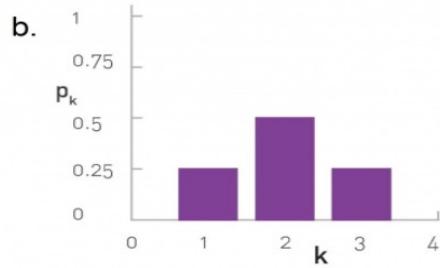
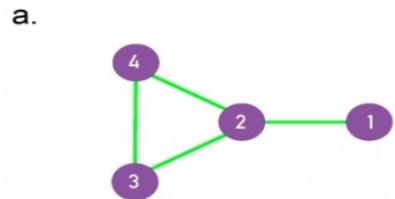
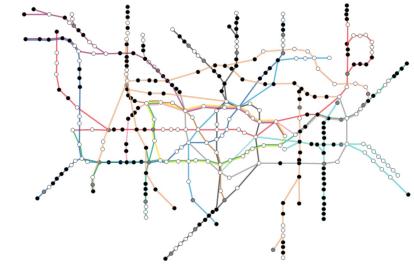
Are there any graphs, which cannot be described?



How to describe a network?

Calculate the number of links for each node.

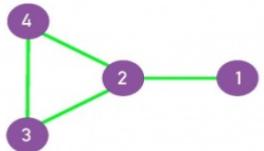
Degree of node A is the number of nodes adjacent with the node A.



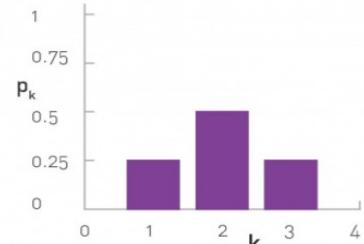
Barabasi book on network science

How to describe a network?

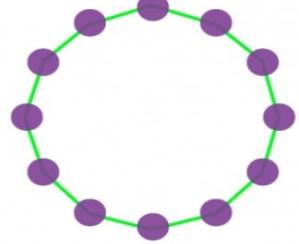
a.



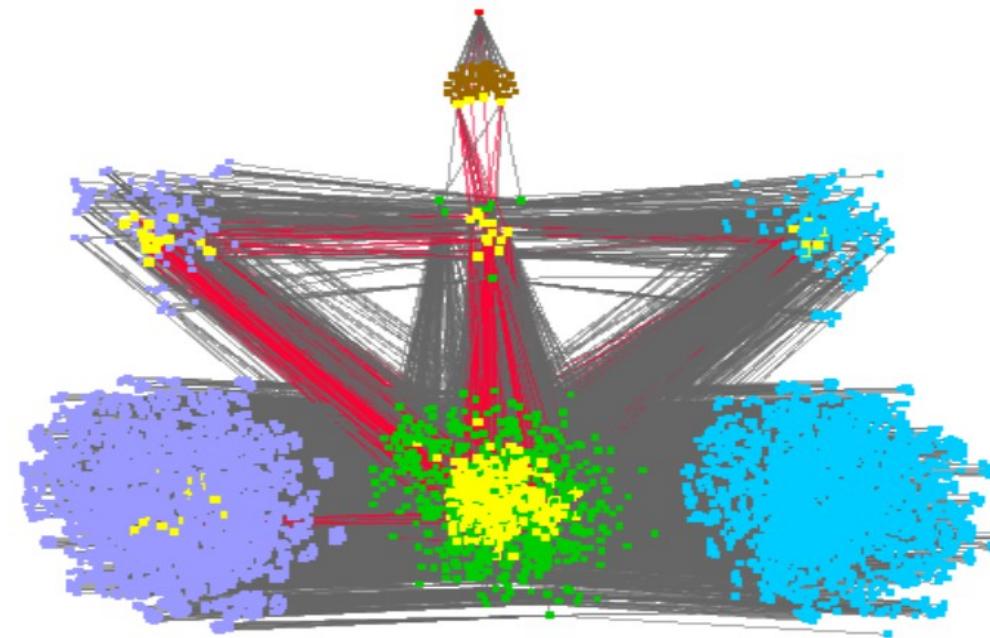
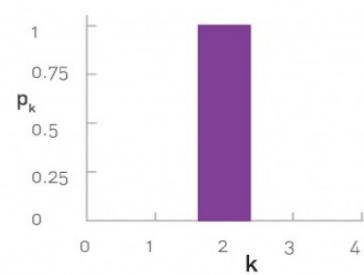
b.



c.



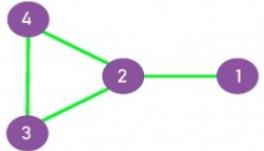
d.



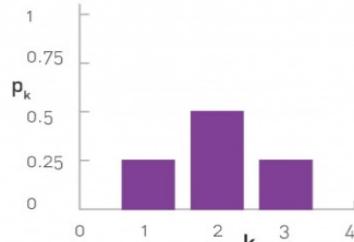
What is degree distribution of larger network?

How to describe a network?

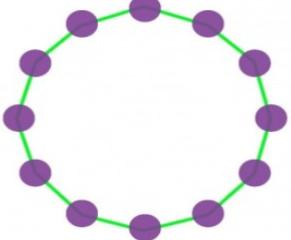
a.



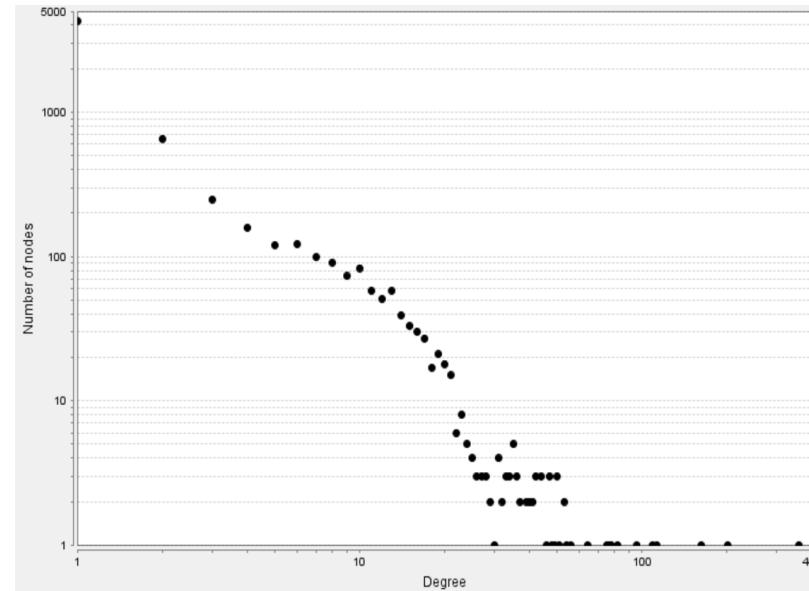
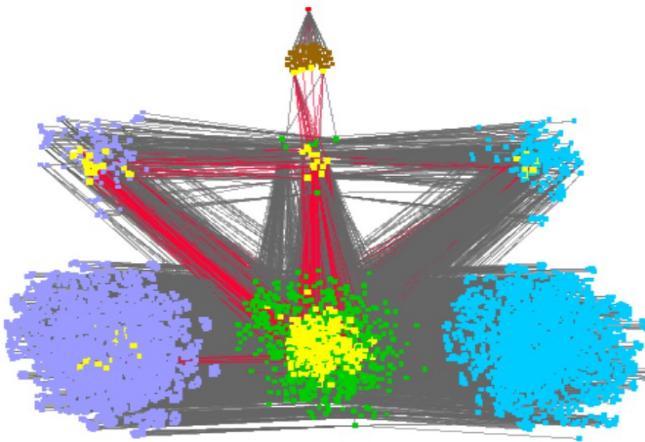
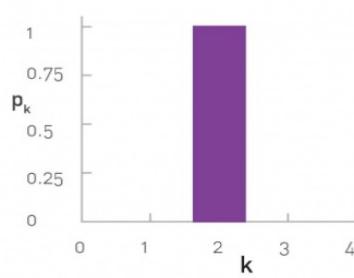
b.



c.

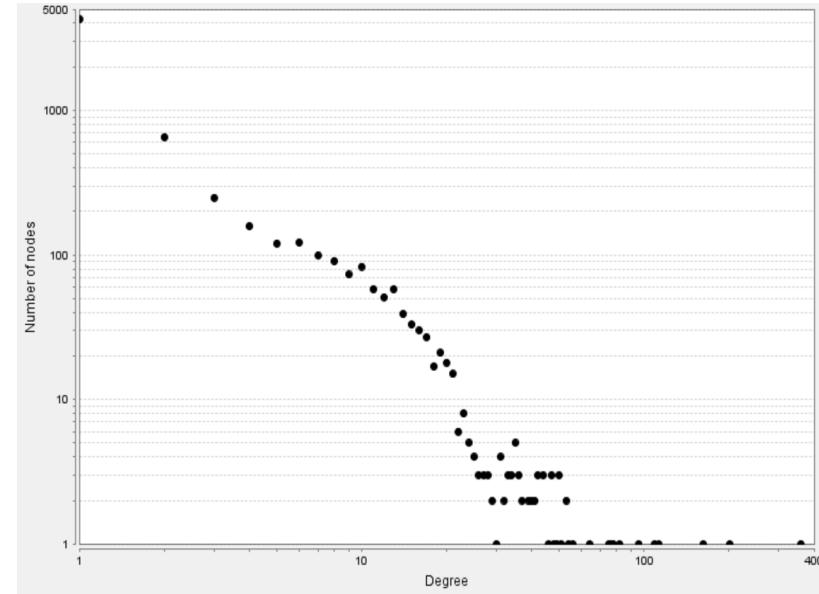
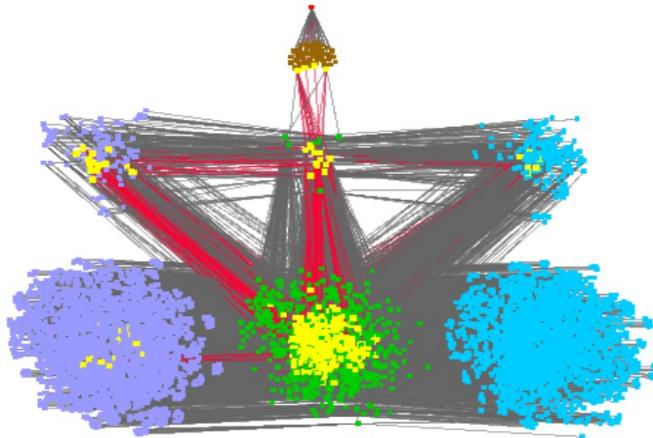


d.



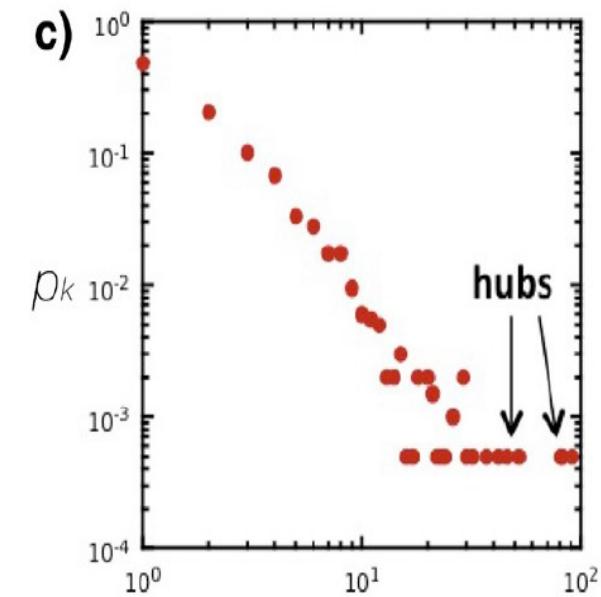
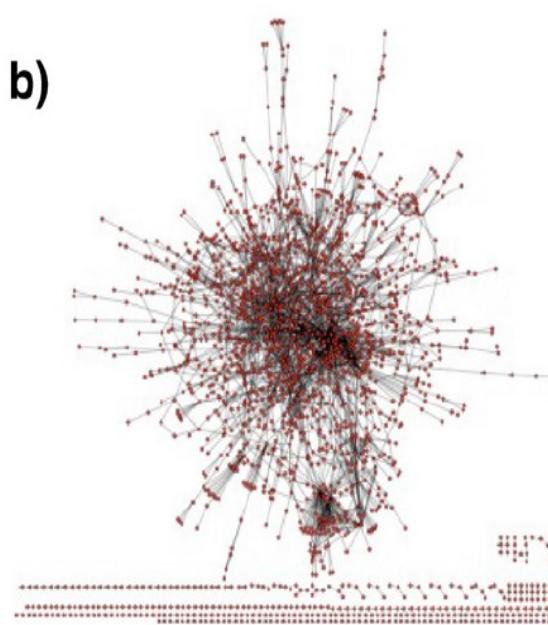
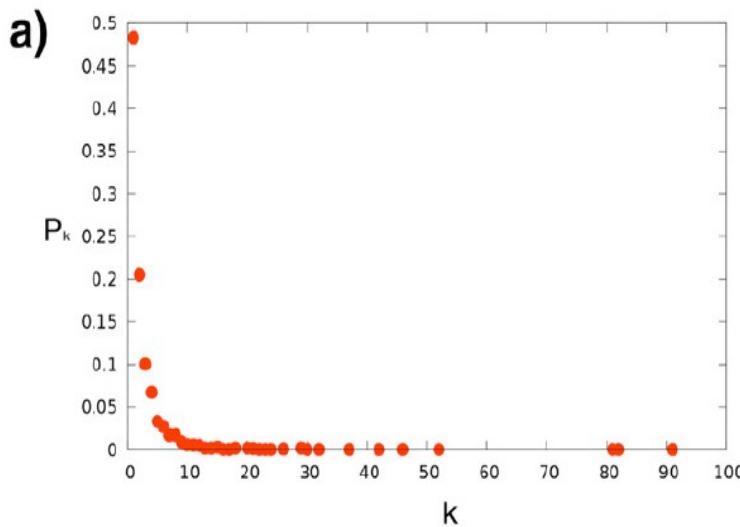
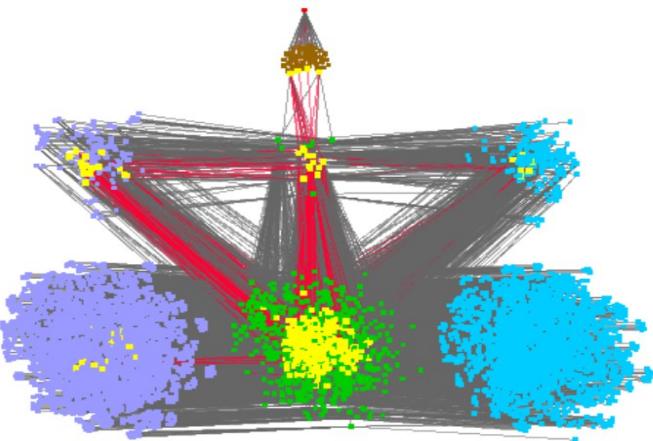
What is degree distribution of larger network?

What is the most typical degree distribution?



Barabasi book on network science
Cytoscape software

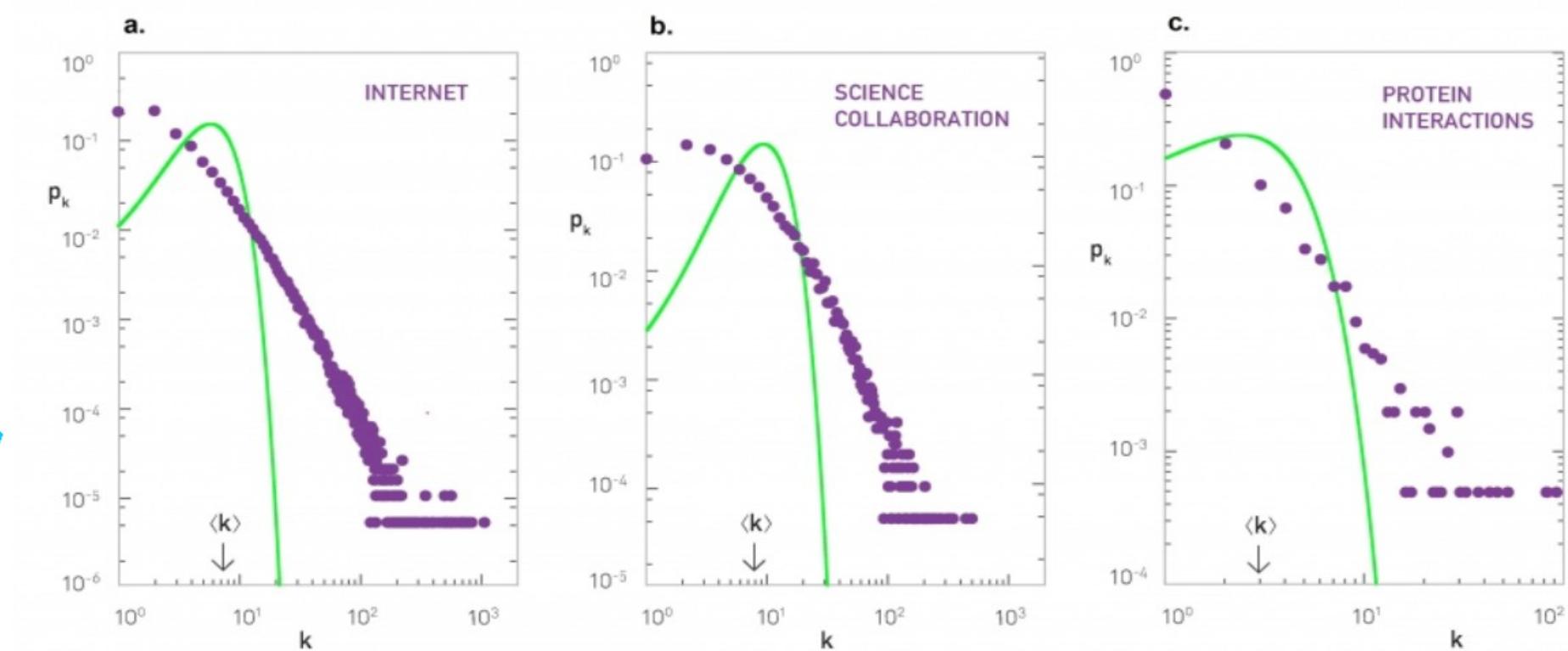
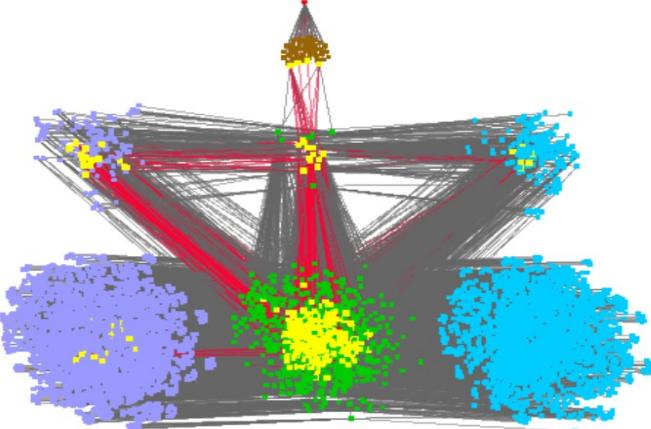
Scale-free networks



"Be careful with power-laws"

Barabasi book on network science
Cytoscape software

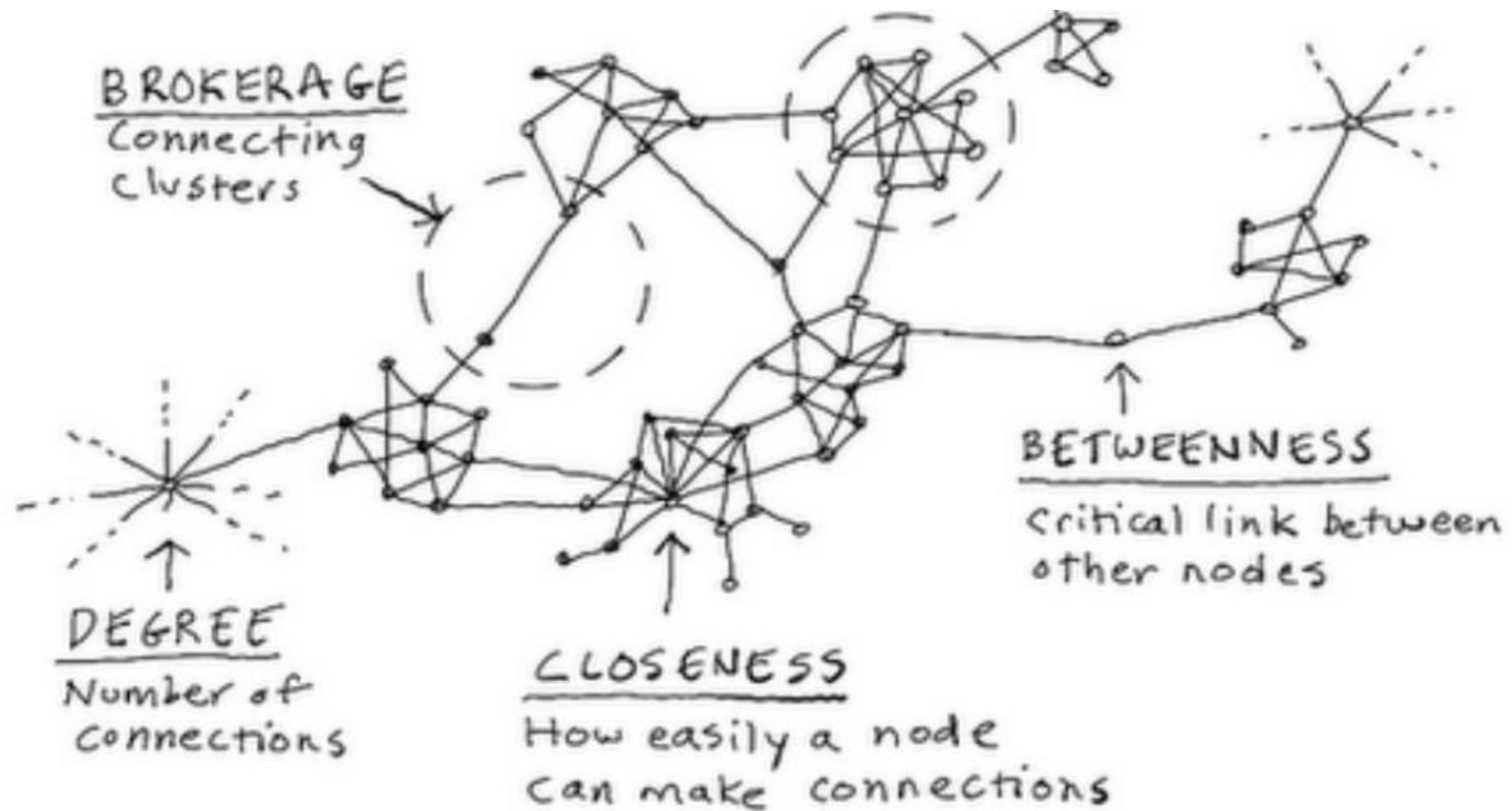
Scale-free networks



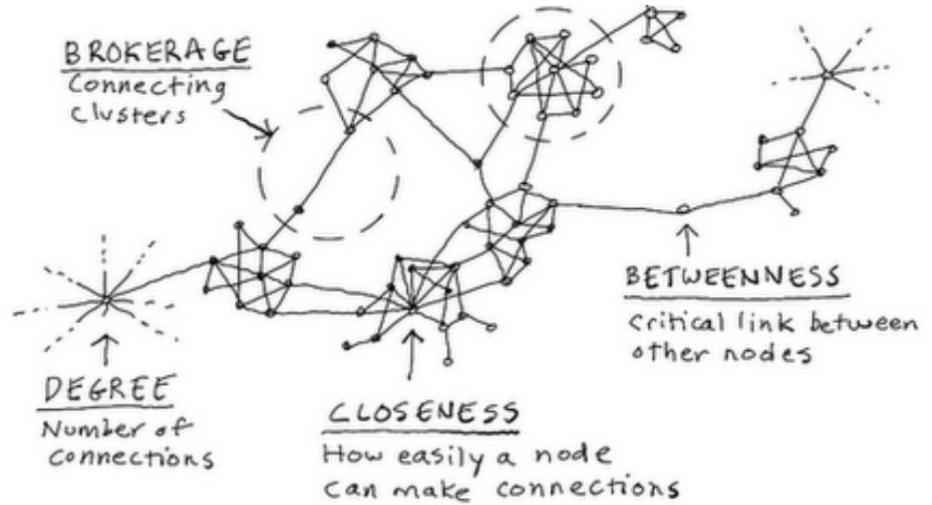
Barabasi book on network science
Cytoscape software

How to describe a network? Network measures

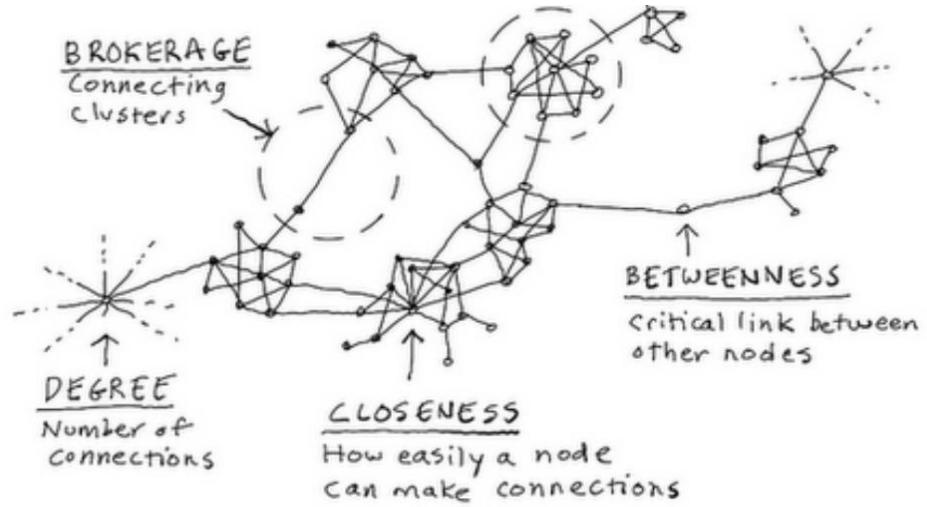
Network measures



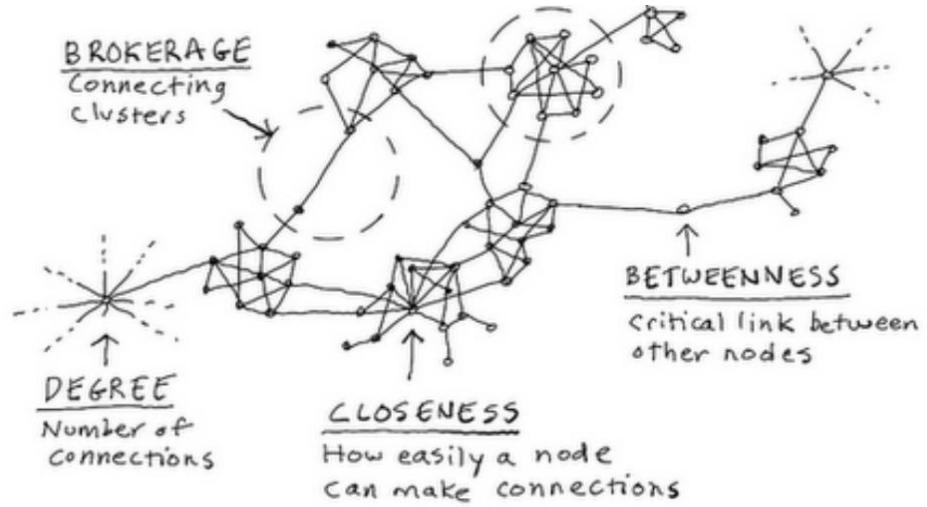
Network measures: clustering



Network measures: degree

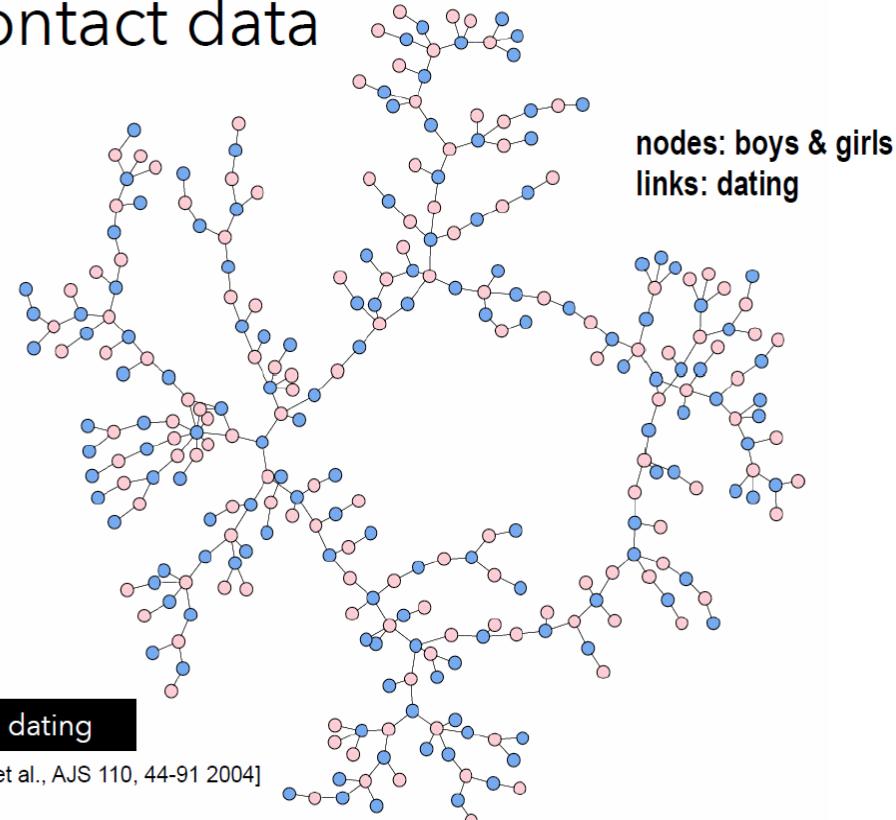


Network measures: betweenness centrality



How to analyze networks with network measures?

contact data



Real-world network examples

Aug 08 2009



Paris
Frankfurt
Amsterdam
Rome
Milan
Moscow
Dublin

Hong Kong
Tokyo Narita
Bangkok
Singapore
Beijing
Manila

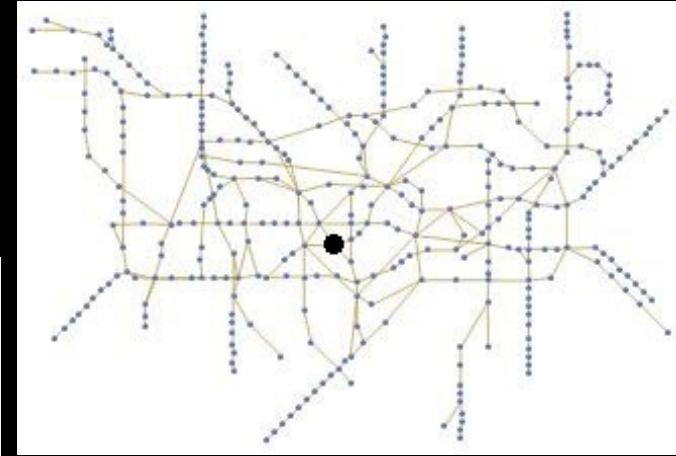
Sydney
Brisbane
Auckland
Perth

Real-world network examples



How can network represent some real data?

Network	Nodes	Links	Directed / Undirected	N	L	$\langle k \rangle$
Internet	Routers	Internet connections	Undirected	192,244	609,066	6.34
WWW	Webpages	Links	Directed	325,729	1,497,134	4.60
Power Grid	Power plants, transformers	Cables	Undirected	4,941	6,594	2.67
Mobile-Phone Calls	Subscribers	Calls	Directed	36,595	91,826	2.51
Email	Email addresses	Emails	Directed	57,194	103,731	1.81
Science Collaboration	Scientists	Co-authorships	Undirected	23,133	93,437	8.08
Actor Network	Actors	Co-acting	Undirected	702,388	29,397,908	83.71
Citation Network	Papers	Citations	Directed	449,673	4,689,479	10.43



Barabasi network book

How can network represent some real data?

SocioPatterns

follow us on [twitter](#)

| ABOUT | GALLERY | PUBLICATIONS | NEWS | PRESS | DATA |

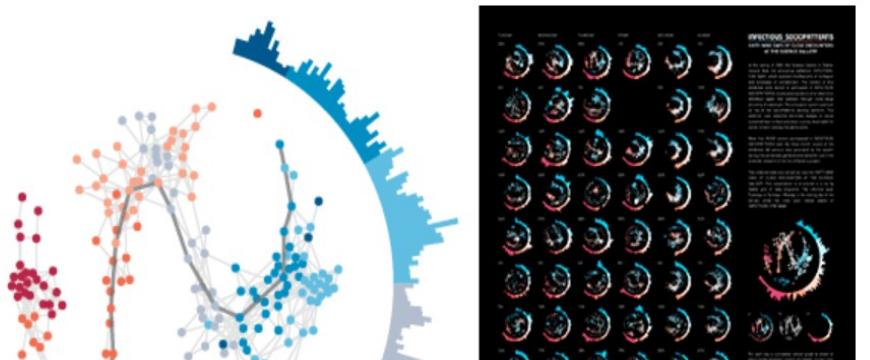
WELCOME

SocioPatterns is an interdisciplinary research collaboration formed in 2008 that adopts a data-driven methodology to study social dynamics and human activity.

Since 2008, we have collected longitudinal data on the physical proximity and face-to-face contacts of individuals in numerous real-world environments, covering widely varying contexts across several countries: schools, museums, hospitals, etc. We use the data to study human behaviour and to develop agent-based models for the transmission of infectious diseases.

We make most of the collected data freely available to the scientific community.

FEATURED: INFECTIOUS SOCIOPATTERNS POSTER



NEWS

New data sets published: co-presence and face-to-face contacts

Through a publication in [EPJ Data Science](#), we have released several new data sets of different types. These datasets can be found on [Zenodo](#).

On the one hand, we have released new temporally resolved data on face-to-face interactions collected in

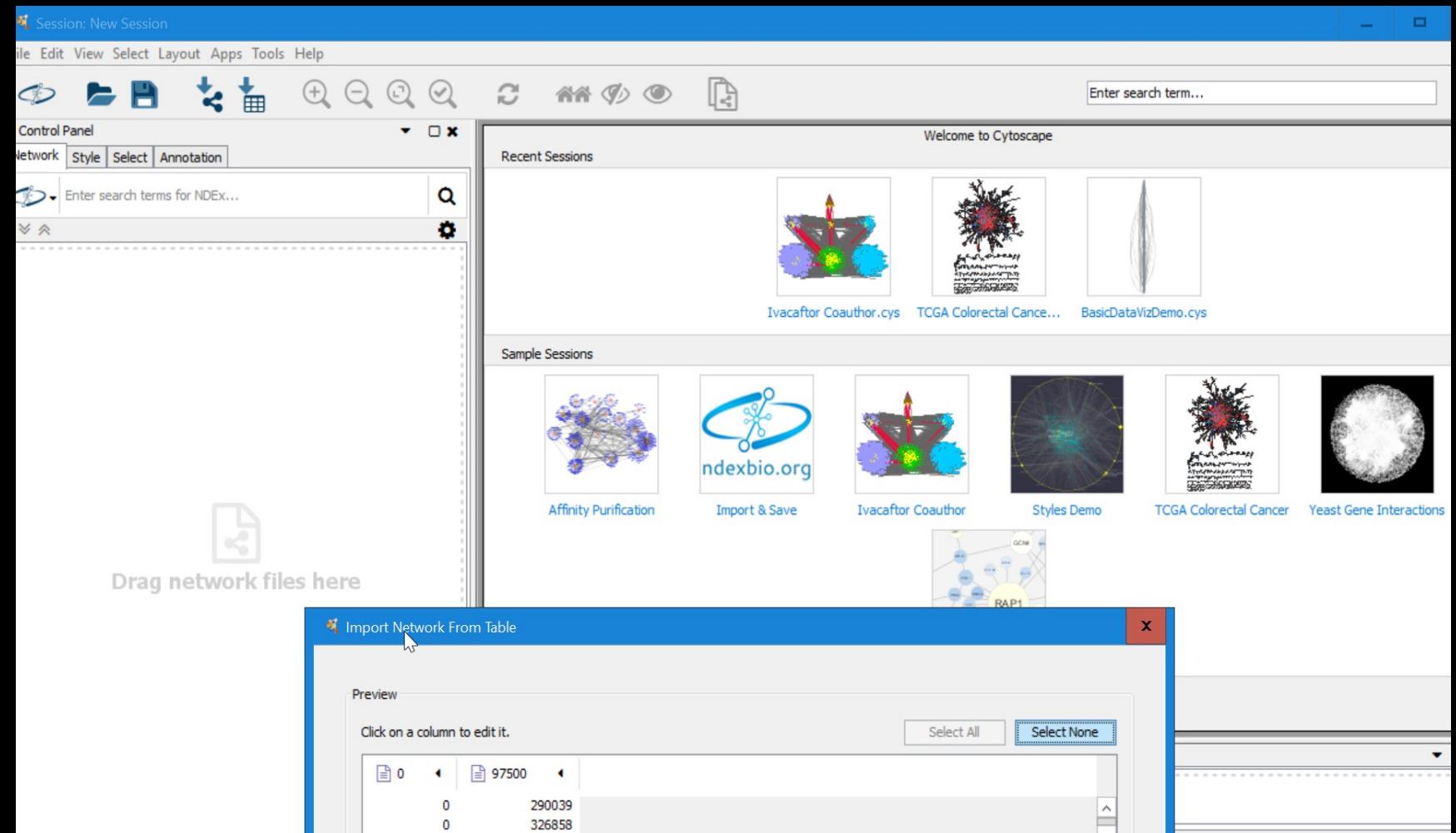
1. the SFHH scientific conference held in 2009, with more than 400 participants to the data collection, a data set that we have already used in several publications such as "[Simulation of an SEIR infectious disease model on the dynamic contact network of conference attendees](#)"
2. an office building (InVS, French Health observatory) in 2015 (following a first data collection performed in 2013, published [here](#)). This data set contains also metadata, i.e., to which department each

<http://www.sociopatterns.org/gallery/>

Hands-on part

Cytoscape networks

Papers discussing
Datasets reading



Hands-on part

Idea:

Each group gets one paper
Each paper → each topic



Hands-on part

Idea:

Each group gets one paper
Each paper → each topic

Neural networks

Citation network

Internet and WWW

Transportation network

Ecological network

Climate networks



Hands-on part

Idea:

Each group gets one paper
Each paper → each topic

Internet and WWW:

Data collected in 1999. Ref: Albert, R., Jeong, H., & Barabasi, A. L. (1999).
Internet: Diameter of the world-wide web. Nature, 401(6749), 130-131

Citation network:

Leskovec, J., Kleinberg, J., & Faloutsos, C. (2007)

Neural networks:

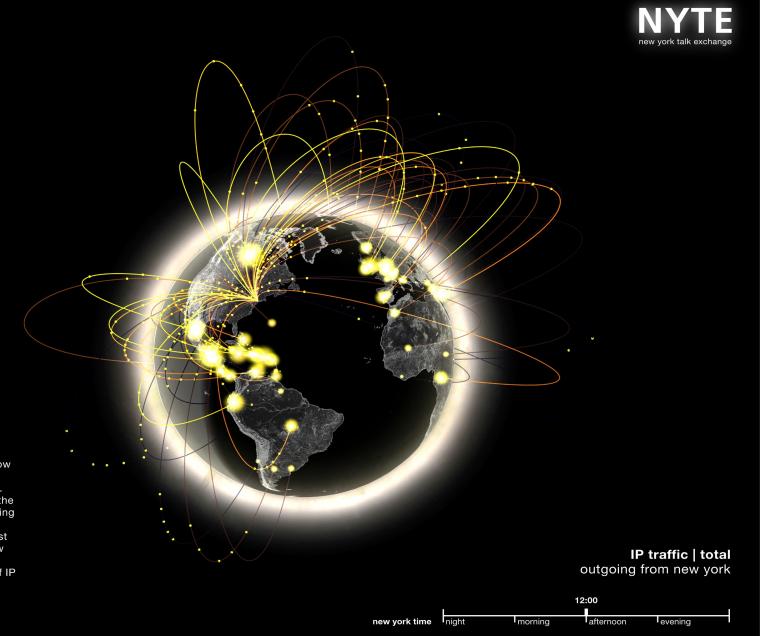
Classes of small-world networks L. A. N. Amaral (2000)

Ecological network

Ecological networks Montoya Sole (2000)

Human networks:

Beamer et al.



Hands-on part

Idea:

Each group gets one paper

Each paper → each topic

Neural networks

Citation network

Internet and WWW

Transportation networks::

M. Barthelemy et al. Optimal traffic networks. J. Stat. Mech. (2006)

Power grid networks:

Amaral et al. (2000)

Climate network

Donges et al. Chaos (2016)

Networks in Climate

Henk A. Dijkstra, Emilio Hernández-García,
Cristina Masoller and Marcelo Barreiro



Take home messages

Networks for description of complex systems

Network measures help to describe complex networks

Network theory on the cross-road of different disciplines:
probability theory, algebra, urbanistics, statistical physics

