Introduction to Network Science

Leonid E. Zhukov

School of Data Analysis and Artificial Intelligence
Department of Computer Science
National Research University Higher School of Economics

Network Science

Class Details

- Instructors: Leonid Zhukov, Ilya Makarov
- Course length: 2 modules
- Module 3: 10 lectures, 10 labs
- Schedule: Tuesday ??, 16.40-19.30
- Website: http://www.leonidzhukov.net/hse/2016/networkscience
- Emails: lzhukov@hse.ru, iamakarov@hse.ru

- Programming: Python, iPython notebooks
- Python libraries: NetworkX
- Visualization: yEd, Gephi
- Software for online lectures: Zoom meeting (www.zoom.us)

Prerequisites

- Discrete Mathematics
- Linear Algebra
- Algorithms and Data Structures
- Probability Theory
- Differential Equations
- Programming in Python

Textbooks

- "Networks: An Introduction". Mark Newman. Oxford University Press, 2010.
- "Networks, Crowds, and Markets: Reasoning About a Highly Connected World". David Easley and John Kleinberg, Cambridge University Press 2010.
- "Social and Economic Networks". Matthew O. Jackson. Princeton University Press, 2010.
- "Social Network Analysis. Methods and Applications". Stanley Wasserman and Katherine Faust, Cambridge University Press, 1994
- "Network Science",Albert-Laszla Barabasi, Cambridge University Press, to be published 2016. http://barabasi.com/networksciencebook/

Reviews

- Statistical mechanics of complex networks, R. Albert and A-L. Barabasi, Rev. Mod. Phys. 74, 47, 2002
- The Structure and Function of Complex Networks, M. E. J. Newman, SIAM Review, 45, pp 167-256, 2003
- Evolution of Networks, S. N. Dorogovtsev and J. F. F. Mendes, Adv. Phys., pp 1079-1187, 2002
- Complex networks: Structure and dynamics, S. Boccaletti et al., Physics Reports, Volume 424, Issue 4-5, p. 175-308, 2006

Topics

1. Statistical properties of networks
2. Network structure
3. Processes on networks
4. Predictions on networks (ML)

Module 3 lectures

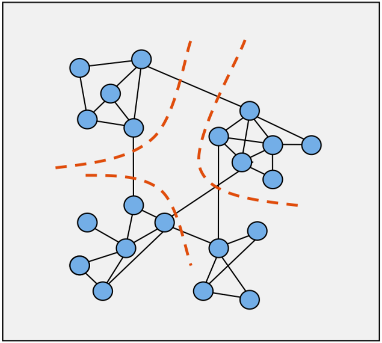
1. Introduction to network science
2. Power laws
3. Random graphs
4. Small world and dynamical growth models
5. Centrality measures
6. Link analysis
7. Structural equivalence
8. Network communities
9. Graph partitioning algorithms
10. Community detection

Network science

- Sociology (SNA)
- Mathematics (Graphs)
- Computer Science (Graphs)
- Statistical Physics (Complex networks)
- Economics (Networks)
- Bioinformatics (Networks)

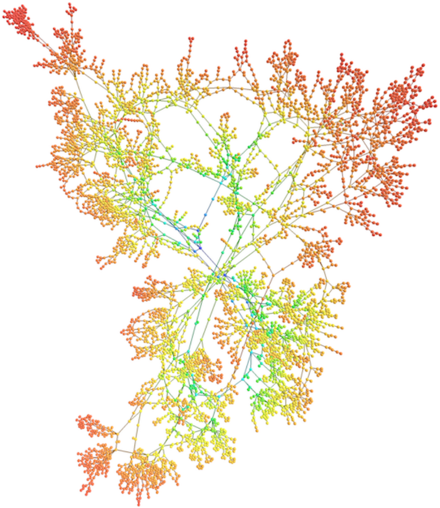
Terminology

- network = graph
- nodes = vertices, actors
- links = edges, relations
- clusters = communities



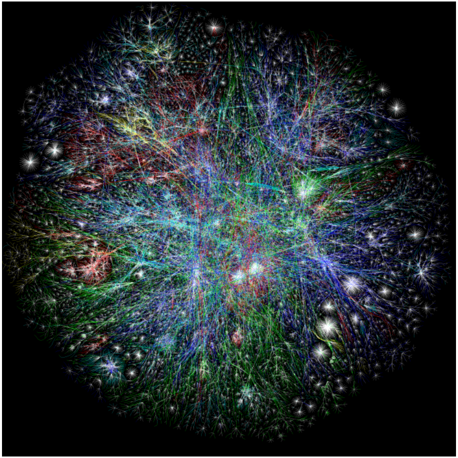
Complex networks

- not regular, but not random
- non-trivial topology
- scale-free networks
- universal properties
- everywhere
- complex systems



Examples: Internet

Internet traffic routing (BGP)



Barret Lyon, 2003

Examples: Political blogs

red-conservative blogs, blue -liberal, orange links from liberal to conservative, purple from conservative to liberal

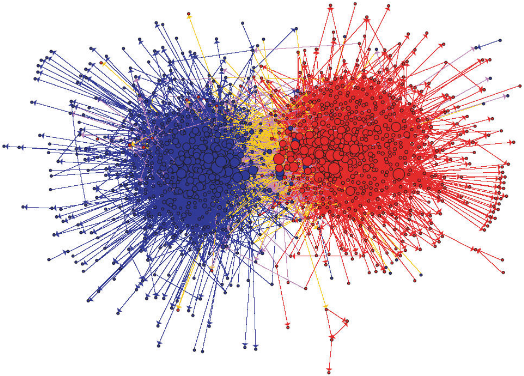


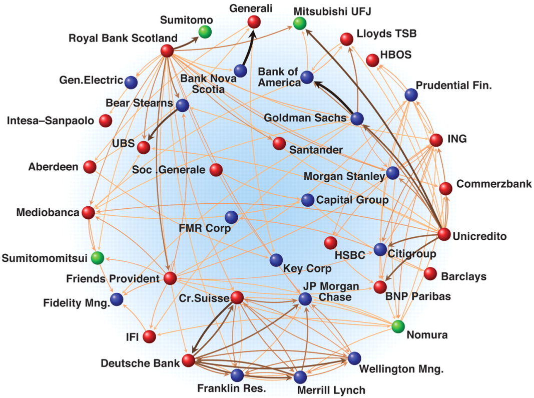
image from L. Adamic, N. Glance, 2005

Examples: Twitter

"#usa" hashtag diffusion, retweets - blue, mentions - orange

image from K. McKelvey et.al., 2012

existing relations between financial institutions



F. Schweitzer, 2009

Examples: Transportation

Zurich public transportation map

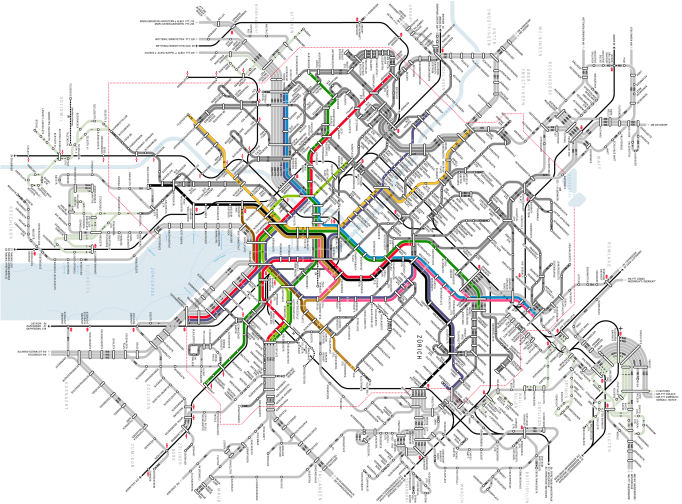
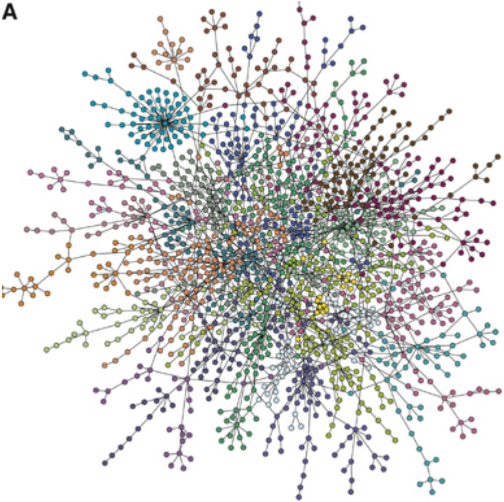


image from http://www.visualcomplexity.com

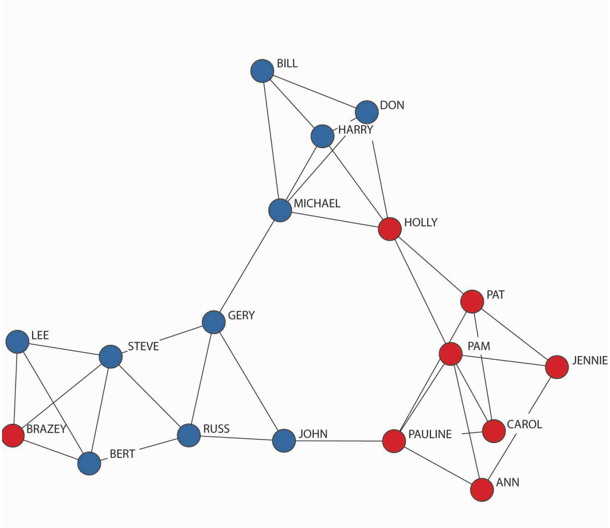
Examples: Biology

Yeast protein interaction network

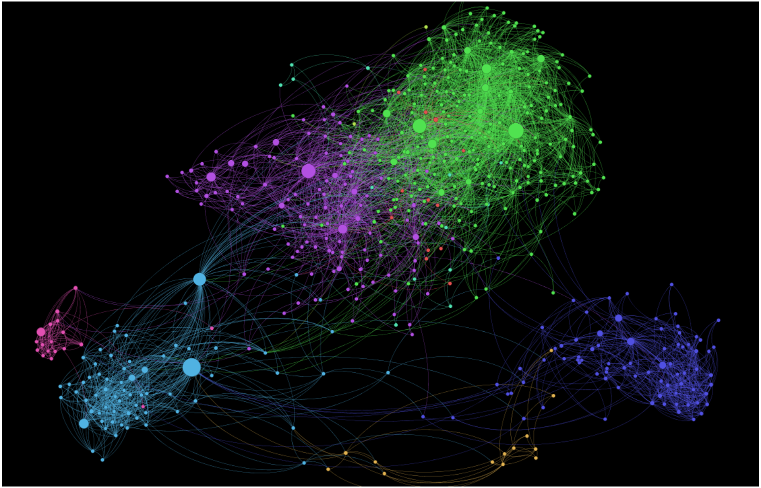


H. Jeong et.al., 2001

Examples: Organization



Examples: Facebook communities structure



Examples: Facebook

Friendship graph 500 mln people

image by Paul Butler, 2010

Complex networks

1. Power law node degree distribution: "scale-free" networks
2. Small diameter and average path length: "small world" networks
3. Hight clustering coefficient: transitivity

Power law

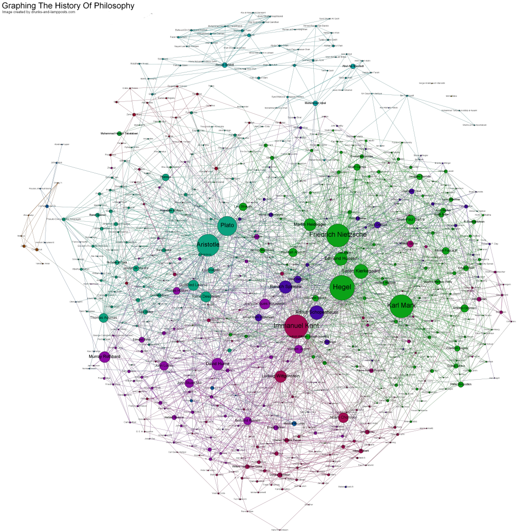


image from http://www.coppelia.io

Power law

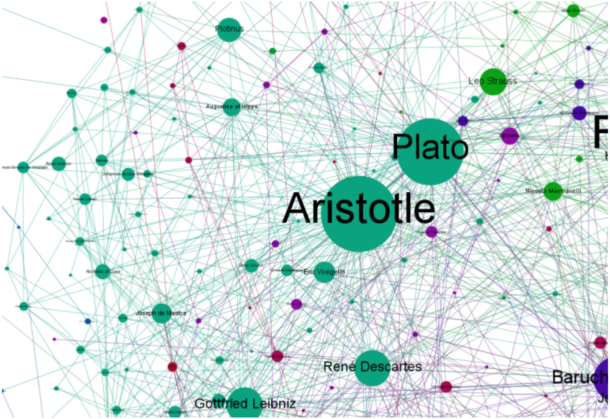


image from http://www.coppelia.io

Power law

Node degree distribution in scale-free network:

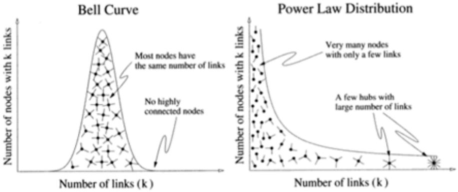
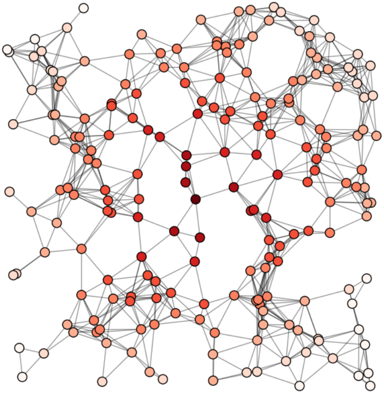


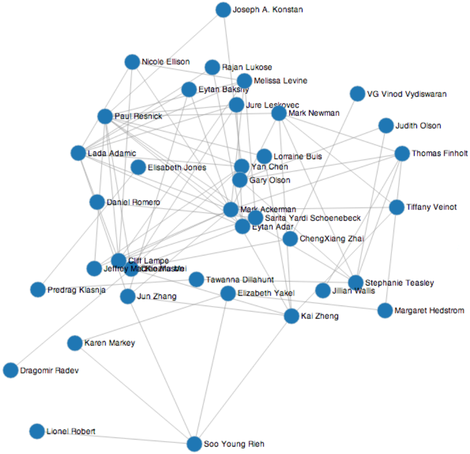
image from A.-L. Barabasi, 2002

High clustering

Random geometric graph



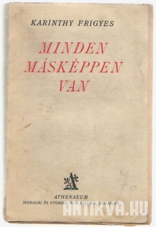
Co-author network

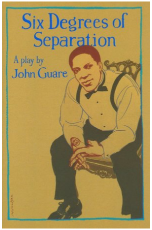


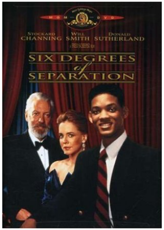
Six degrees of separation

"Any two people are on average separated no more that by six intermediate connections"

- Frigyes Karinthy, short story "Lancszemek" ("Chain-Links"), 1929.
- John Guare play (1991) and movie (1993), "Six Degrees of Separation"







Small world

© Al Satterwhite

An Experimental Study of the Small World Problem*

JEFFREY TRAVERS

Harvard University

AND

STANLEY MILGRAM

The City University of New York

Arbitrarily selected individuals (N=296) in Nebraska and Boston are asked to generate acquaintance chains to a target person in Massachusetts, employing "the small world method" (Milgram, 1967). Sixty-four chains reach the target person. Within this group the mean number of intermediaries between starters and targets is 5.2. Boston starting chains reach the target person with fewer intermediaries than those starting in Nebraska; subpopulations in the Nebraska group do not differ among themselves. The funneling of chains through sociometric "stars" is noted, with 48 per cent of the chains passing through three persons before reaching the target. Applications of the method to studies of large scale social structure are discussed.

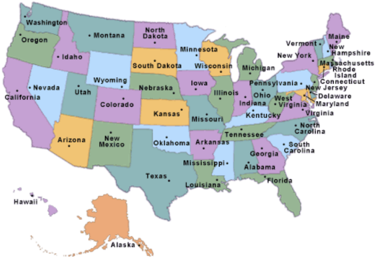
- "The small-world problem". Stanley Milgram, 1967
- "An experimental study of the small world problem", Jeffrey Travers, Stanley Milgram, 1969

Stanley Milgram's 1967 experiment

HOW TO TAKE PART IN THIS STUDY

1. ADD YOUR NAME TO THE ROSTER AT THE BOTTOM OF THIS SHEET, so that the next person who receives this letter will know who it came from.
2. DETACH ONE POSTCARD. FILL IT OUT AND RETURN IT TO HARVARD UNIVERSITY. No stamp is needed. The postcard is very important. It allows us to keep track of the progress of the folder as it moves toward the target person.
3. IF YOU KNOW THE TARGET PERSON ON A PERSONAL BASIS, MAIL THIS FOLDER DIRECTLY TO HIM (HER). Do this only if you have previously met the target person and know each other on a first name basis.
4. IF YOU DO NOT KNOW THE TARGET PERSON ON A PERSONAL BASIS, DO NOT TRY TO CONTACT HIM DIRECTLY. INSTEAD, MAIL THIS FOLDER (POSTCARDS AND ALL) TO A PERSONAL ACQUAINTANCE WHO IS MORE LIKELY THAN YOU TO KNOW THE TARGET PERSON. You may send the folder

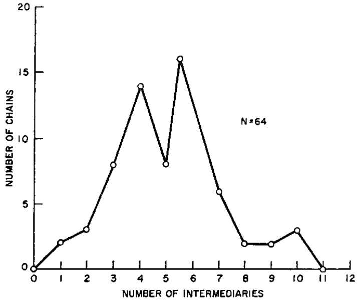
- Starting persons:
  - 296 volunteers, 217 sent
  - 196 in Nebraska
  - 100 in Boston
- Target person - Boston stockbroker
- Information given: target name, address, occupation, place of employment, college, hometown



J. Travers, S. Milgram, 1969

Stanley Milgram's 1967 experiment

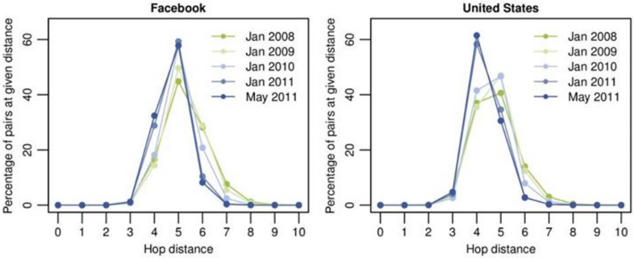
- Reached the target $N = 64(29\%)$
- Average chain length $\langle L \rangle = 5.2$
- Channels:
  - hometown $\langle L \rangle = 6.1$
  - business contacts $\langle L \rangle = 4.6$
  - from Boston $\langle L \rangle = 4.4$
  - from Nebraska $\langle L \rangle = 5.7$



J. Travers, S. Milgram, 1969

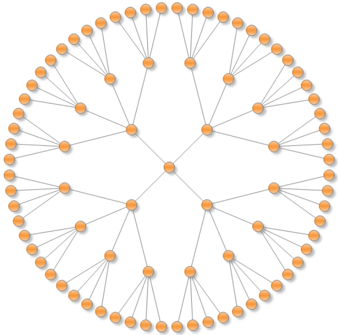
Small world

- Email graph:
  D. Watts (2001), 48,000 senders, $\langle L \rangle \approx 6$
- MSN Messenger graph:
  J. Lescovec et al (2007), 240mln users, $\langle L \rangle \approx 6.6$
- Facebook graph:
  L. Backstrom et al (2012), 721 mln users, $\langle L \rangle \approx 4.74$



figures from L.Backstrom, 2012

Simple model



An estimate: $z^d = N$, $d = \log N / \log z$
$N \approx 6.7$ bln, $z = 50$ friends, $d \approx 5.8$.

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- Scale free networks. A.-L. Barabasi, E. Bonabeau, Scientific American 288, 50-59 (2003)
- Scale-Free Networks: A Decade and Beyond. A.-L. Barabasi, Science 325, 412-413 (2009)
- The Physics of Networks. Mark Newman, Physics Today, November 2008, pp. 3338.

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- An Experimental Study of the Small World Problem. J. Travers and S. Milgram. . Sociometry, vol 32, No 4, pp 425-433, 1969
- Planetary-Scale Views on a Large Instant-Messaging Network. J. Leskovec and E. Horvitz. , Procs WWW 2008
- Four Degrees of Separation. L. Backstrom, P. Boldi, M. Rosa, J. Ugander, S. Vigna, WebSci '12 Procs. 4th ACM Web Science Conference, 2012 pp 33-42