Networks and stability

Part 1A. – Network topology

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1. network topology

2. network dynamics

3. examples for networks

4. synthesis (complex equilibria, games, network evolution, trans-network effects)

1. network topology (II.20-27.)

2. network dynamics (III.6.-13.)

(III.20.-27. no lectures)

3. examples for networks (IV.3.-10.)

(IV.17. Easter)

4. synthesis (IV.24., V.1. holiday, **V.8.)**

(V.13. consultation)

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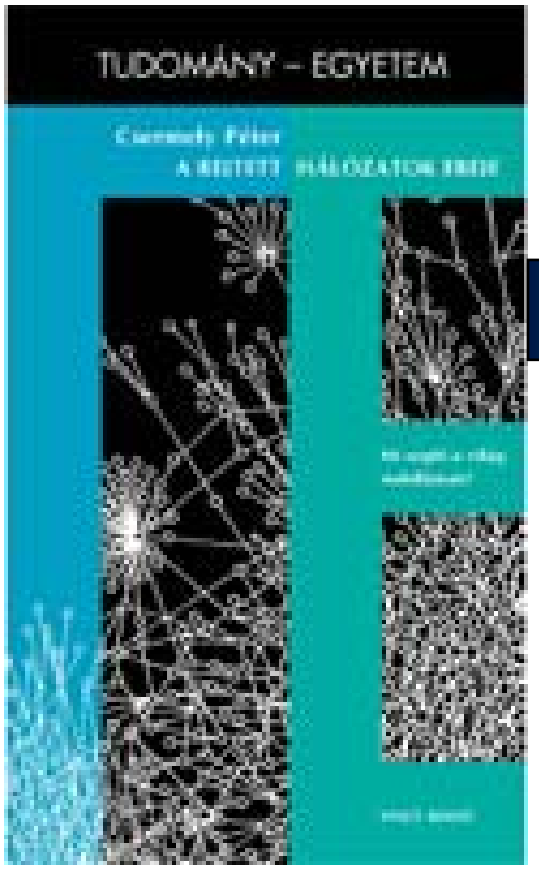
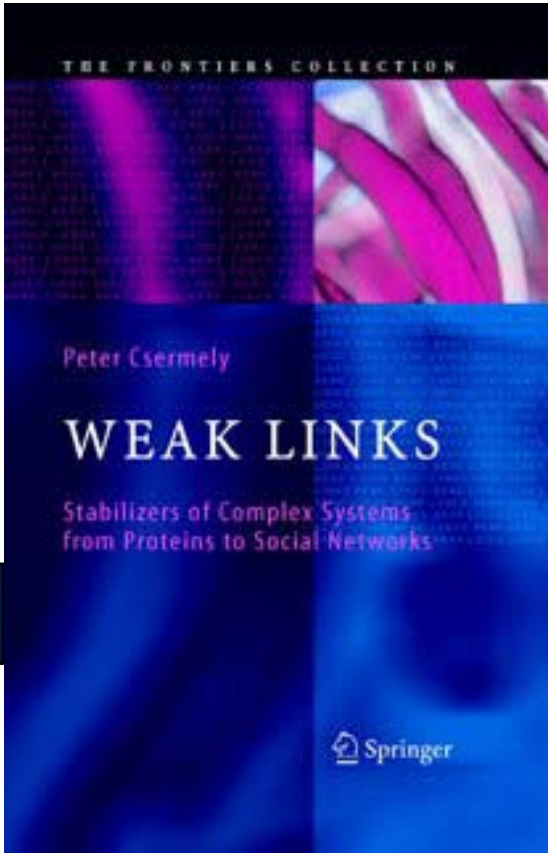


Hungarian

Vince Publisher, Budapest, 2005

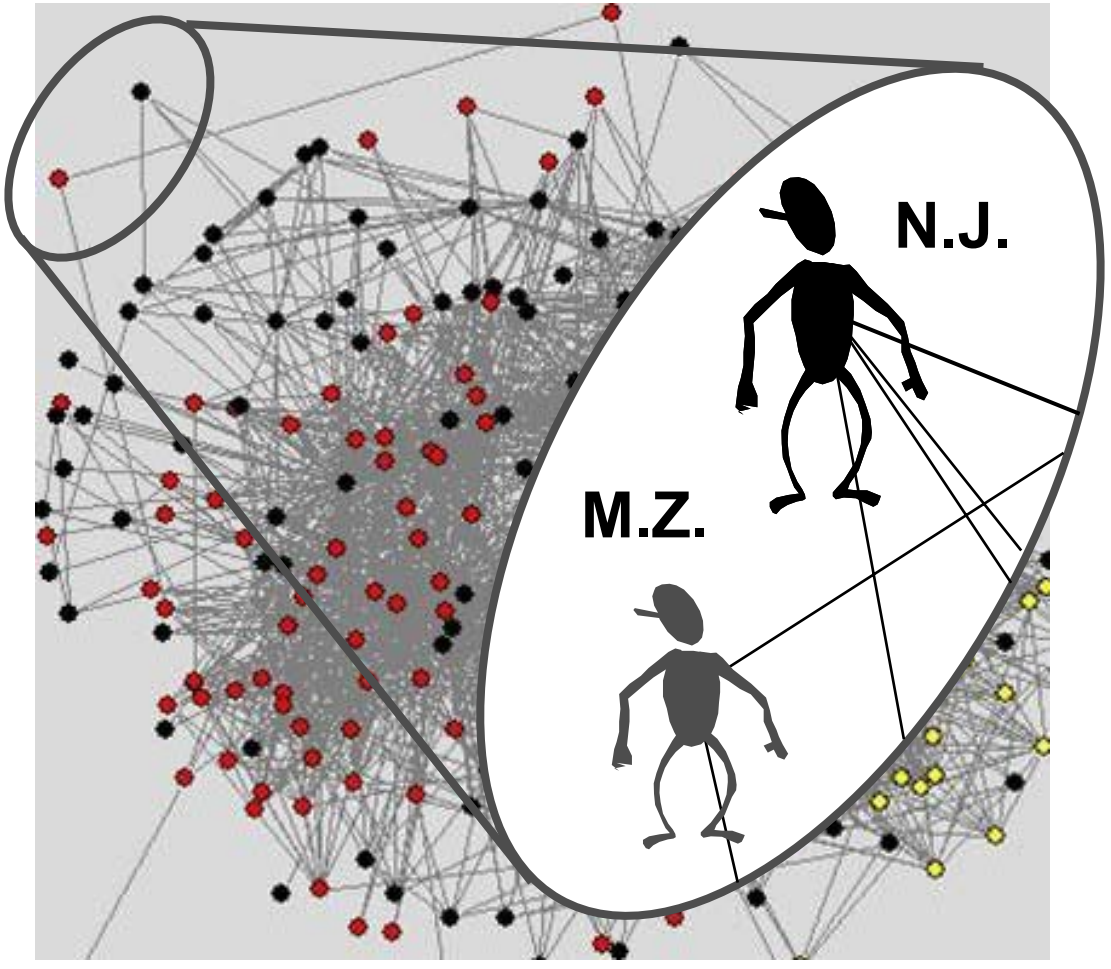


English

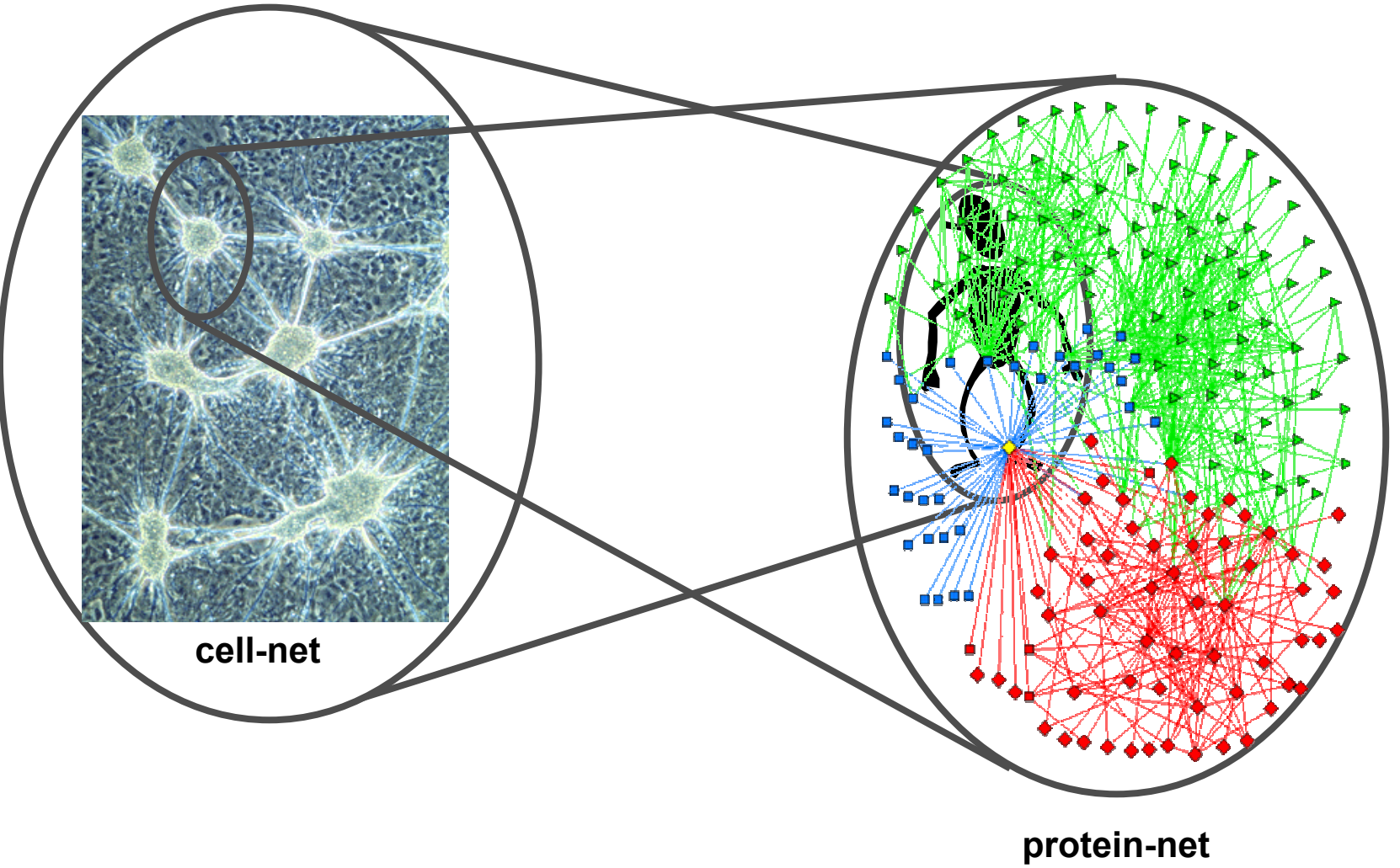
Springer, 2006

www.weaklink.sote.hu

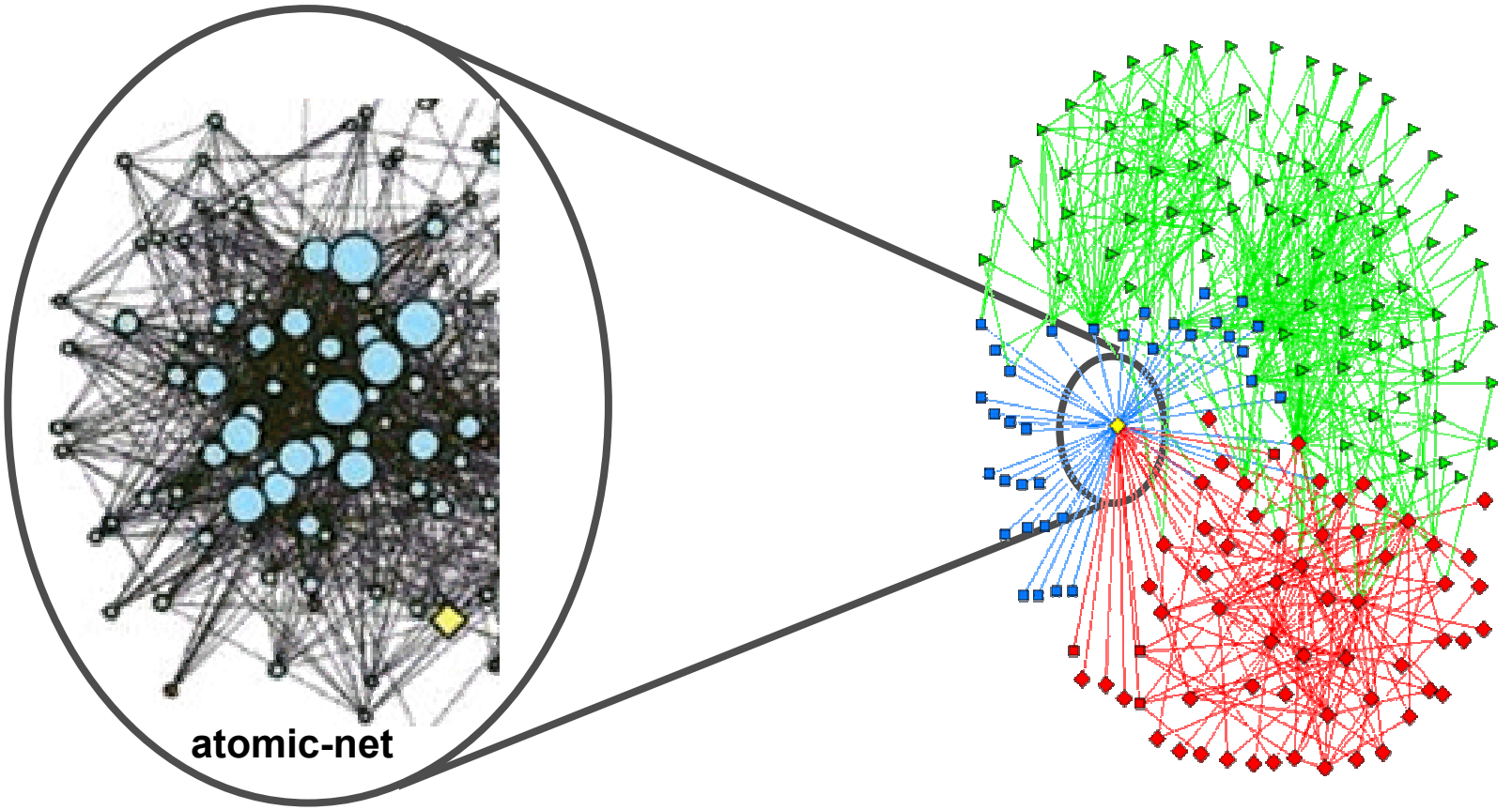
Networks are embedded



Networks are embedded



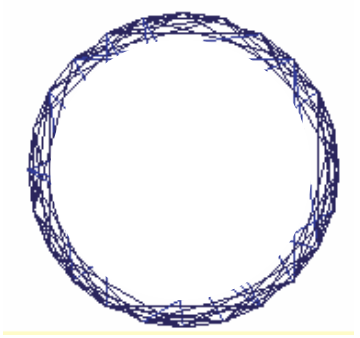
Networks are embedded



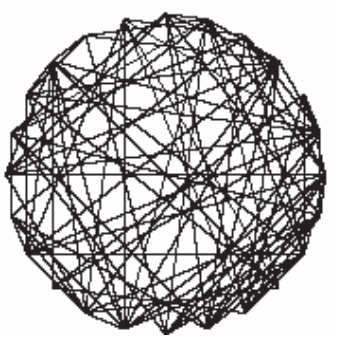
Network topology

- **small worlds**
- scale-free degree distribution
- network communities
- network skeleton
- hierarchy and nestedness

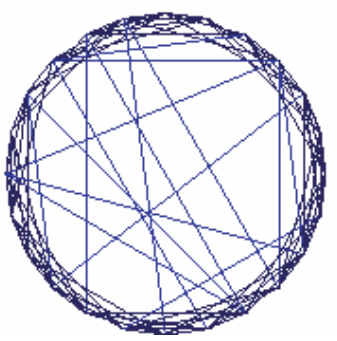
Major classes of network topology



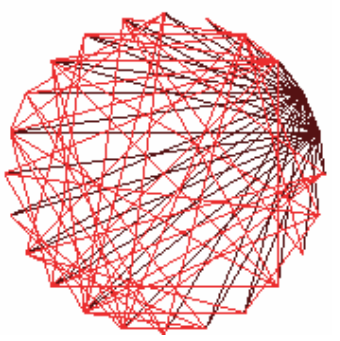
regular



random



small-world



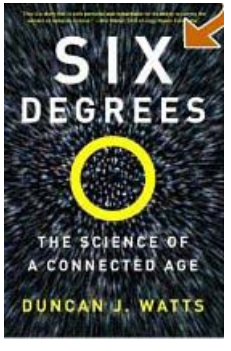
scale-free

Sporns et al. Trends Cogn Sci. 8, 418

The Milgram-experiment

96 participants from Nebraska,
1 target in Boston,
18 letter chains via friends
(first-name-basis)
Psych. Today 1, 62; 1967

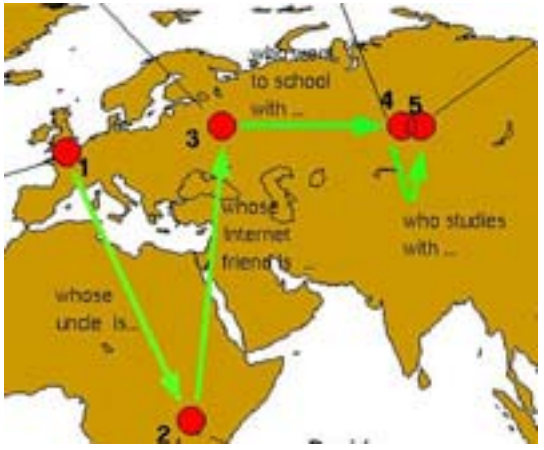
Six degrees of separation



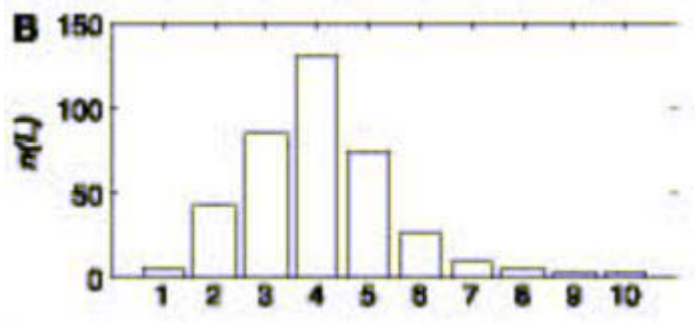
100^6 = >100 x
the total population
of the Earth

Frigyes Karinthy
(1929) Five degrees

Repeated Milgram-experiments

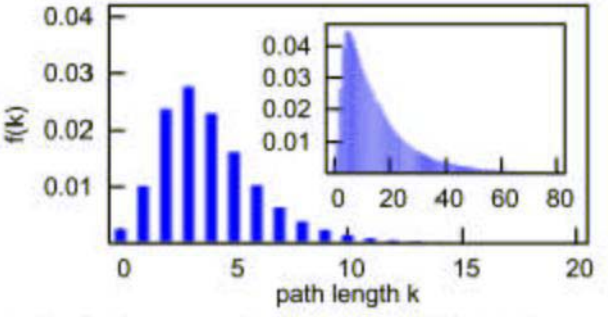


60,000 participants,
166 countries,
18 targets,
384 email chains
Science 301, 827; 2003

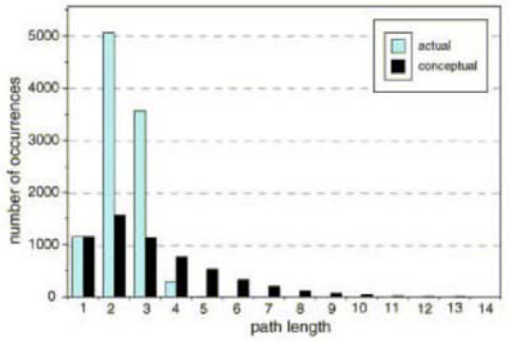


4 degrees
(5-7 if corrected
for drop-outs)

www.livejournal.com
500,000 US participants,
500,000 trials
PNAS 102, 11623; 2005



Milgram-experiment: background



52% wrong guesses

Social Networks 28, 85; 2006

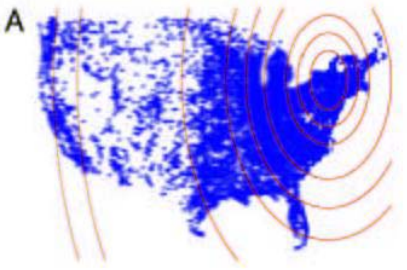
Table 1. Comparison of four *E. coli* network analyses

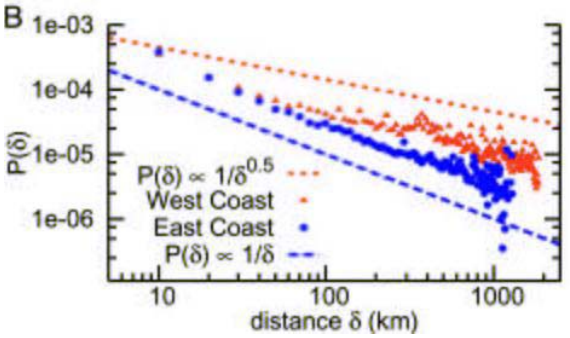
	Jeong et al. (7), directed	Wagner and Fell (5), undirected	Ma and Zeng (8), directed	This study, (un)directed
Top 10 hubs	H_2O	L-glutamate	glycerate 3P	carbon dioxide
	ADP	pyruvate	D-ribose 5P	pyruvate
	P	CoA	acetyl CoA	acetyl CoA
	ATP	α-keto glutarate	pyruvate	ATP
	L-glutamate	L-glutamine	D-xylulose 5P	D-glucose
	$NADP^+$	L-aspartate	D-fructose 6P	L-glutamate
	PP	acetyl CoA	5P-D-ribose 1PP	D-galactose
	NAD^+	phosphoribosyl PP	L-glutamate	CoA
	NADPH	tetrahydrofolate	D-glyceraldehyde 3P	S-adenosyl L-methionine
	NADH	succinate	L-aspartate	D-5-phosphoribosyl-1P
AL	3.2	3.8	8.2	8.4 (8.0)

The top 10 hub metabolites and ALs reported in each study. Wagner and Fell (5) computed several versions of the network; the one shown here is the substrate-based network where ATP, ADP, NAD, NADP, NADH, NADPH, carbon dioxide, ammonia, sulfate, thioredoxin, (ortho) phosphate (P), and pyrophosphate (PP) are removed.

avg. length may grow to 8

PNAS 101, 1543; 2004





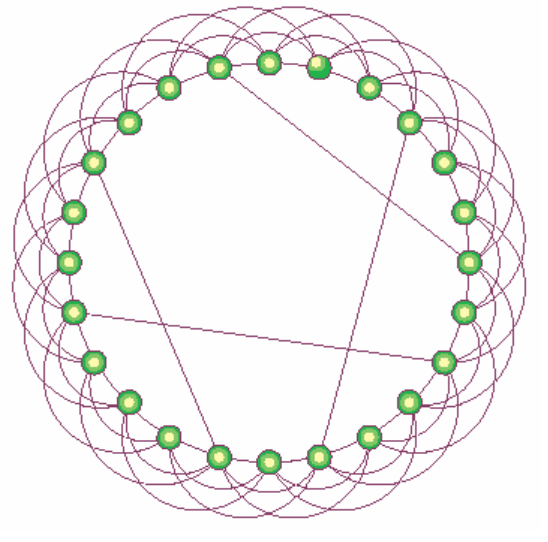
geographic distance directs firendship circles

PNAS 102, 11623; 2005

+ social dimensions

Expansion of the small-world concept

Duncan Watts Steve Strogatz



Nature 393, 440; 1998

high clustering coefficient
AND small characteristic path length

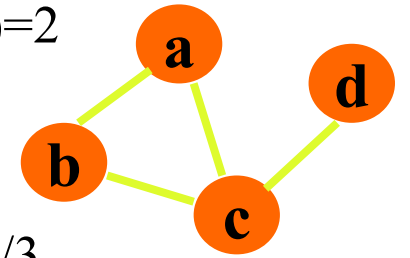
general model
examples:
- *C. elegans* neurons
- US power grid
- film actor collaboration net

Path length and clustering

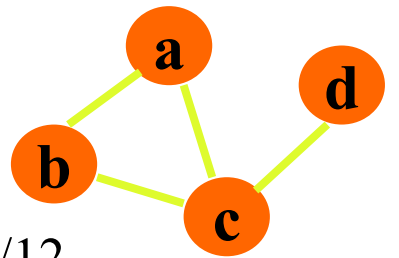
Characteristic path length:
average of shortest pathlengths

Random graphs: small

- D(ab)=1, D(ac)=1, D(ad)=2
- D(bc)=1, D(bd)=2
- D(cd)=1
- L=(1+1+2+1+2+1)/6 = 4/3



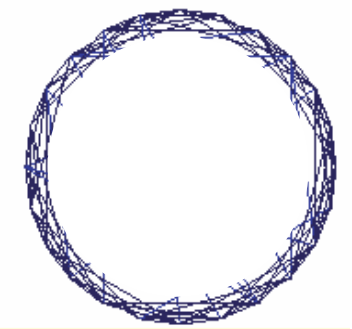
- C(a)=C(b)=1
- C(c)=1/3
- C(d)=0
- Cavg=(1+1+1/3+0)/4 = 7/12

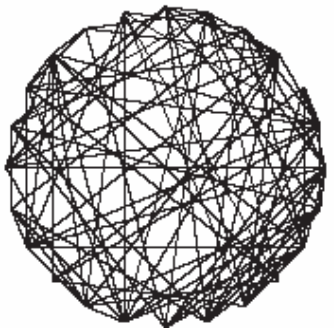


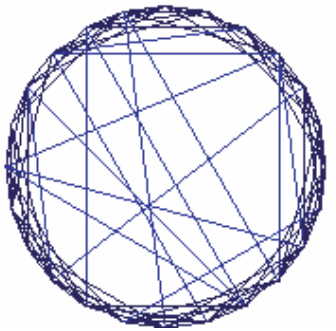
Clustering coefficient:
connection of neighbors

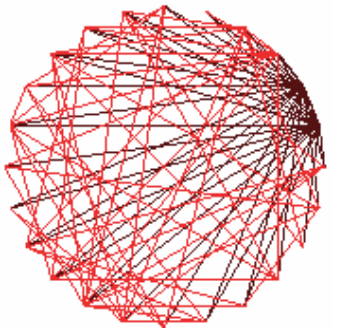
Regular lattices: large

Major classes of network topology









regular random **small-world** **scale-free**

the small world network gives low cost global connections

?

Sporns et al. Trends Cogn Sci. 8, 418

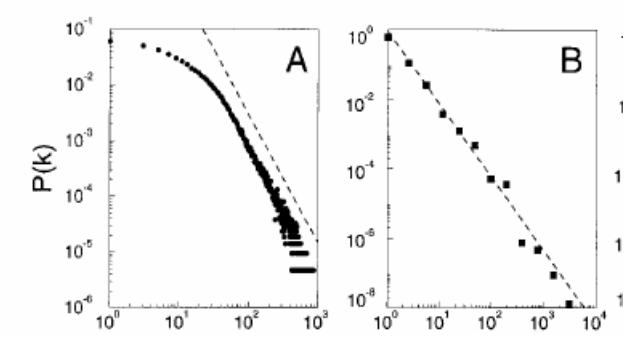
Network topology

- small worlds
- **scale-free degree distribution**
- network communities
- network skeleton
- hierarchy and nestedness

Scale-free degree distribution

László Barabási Réka Albert

degree-distribution

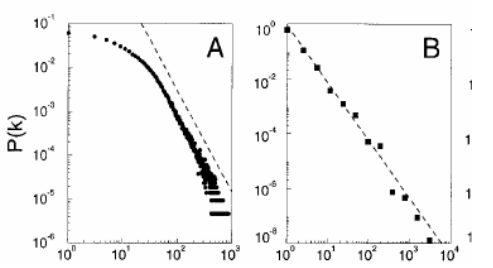


network model:
preferential attachment
(Matthew-effect, Pareto-law)
generality for actors, power grid, www
Science 286, 509; 1999

$P = a\ k^{-\alpha}$ (P probability, a constant, k degree, α exponent)

$\lg P = \lg a - \alpha \lg k$

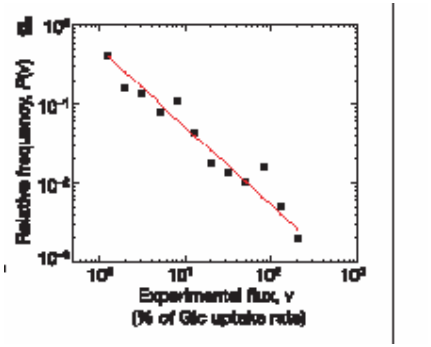
How to make networks with scale-free degree distribution?



- preferential attachment
  - variable attractivity (fitness)
  - winner takes all (star-net)
  - aging networks (random net)
- duplication and divergence

Generality of scale-free distributions

link-strength

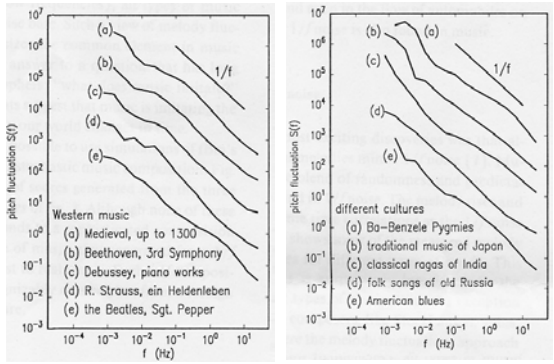


Nature 427, 839; 2004

Levy-flights

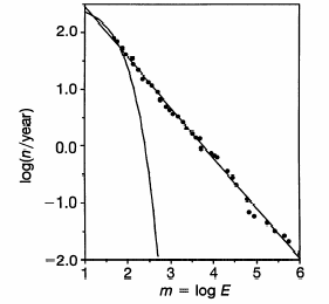
Can J. Zool. 80, 436; 2002

music



Nature 258, 317; 1975

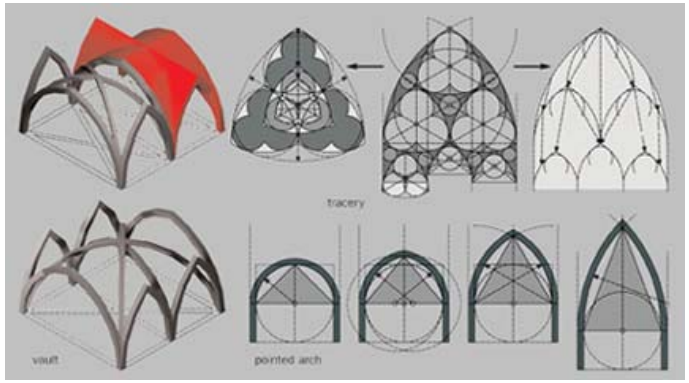
probability, Noe-effect



PNAS 92, 6689; 1995
Kohlrausch, 1854
Leiden-jars
cumulative wins
Bernoulli, 1738

town size Zipf-law
rain, lightning, tic
sexual contacts
earthquakes,
Gutenberg-Richter law
science papers
Lotka-law

fractals, architecture



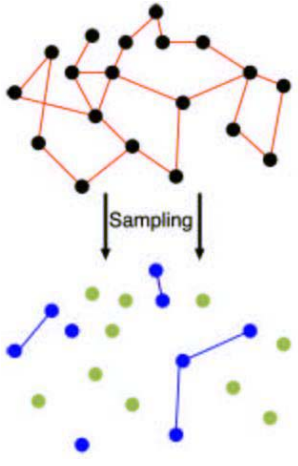
www.iemar.tuwien.ac.at/modul23/Fractals

Dangers of scale-free distributions

- must span many scales

  (network must be large enough)
- a line can be fitted to many curves…

  (log-normal, gamma, stretched exponential)
- cumulative plots are much better
- sampling bias
- unspecific data may cover real data
- distinct parts of networks are different



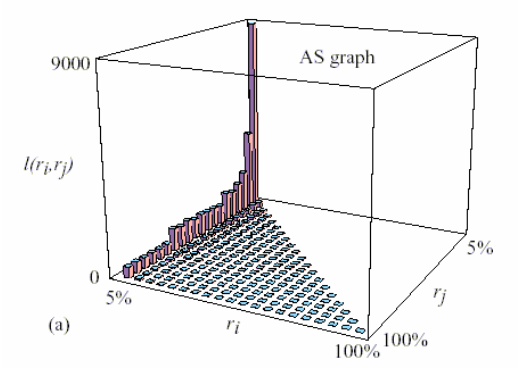
PNAS 102, 4221; 2005

Reasons behind the generality of scale-free distributions

- preferential attachment
- cumulative success of consecutive tasks
- self-organization of matter in the Universe

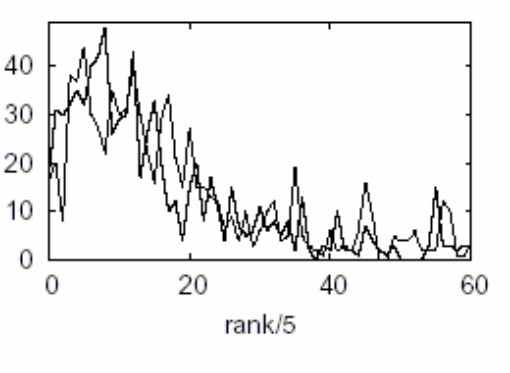
Network clubs

Rich-club: hubs associate with hubs (assortativity: social nets)



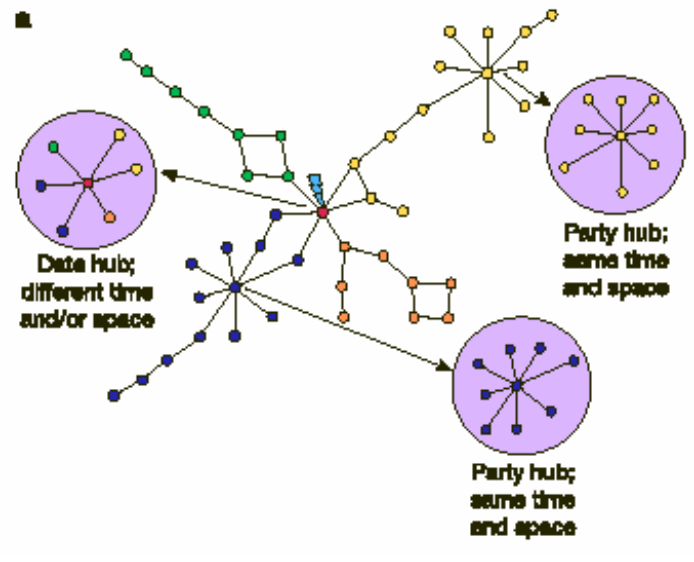
Zhou and Mondragon
IEEE Comm. Lett. 8, 180

Talented(VIP)**-club:** isolated top rank associates with hubs



Masuda and Konno
Social Networks, in press

Date hubs and party hubs



Han et al. Nature 430, 88

yeast protein network

–date hubs

–party hubs