The Abdus Salam International Centre for Theoretical Physics

2234-9

Meeting of Modern Science and School Physics: College for School Teachers of Physics in ICTP

27 April - 3 May, 2011

Econophysics: how can we describe a healthy economy and predict a financial crisis

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Econophysics: Financial Networks and can we predict Financial Crisis ?

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Summer School: Modern Science and School Physics, Trieste, ICTP, 27 April- 3 May, 2011

New Paradigm: Networks, example #1: Network of Roads

Econophysics

- Econophysics is an interdisciplinary research field, applying methods developed in physics
- Aim: to solve problems in economics, usually those including uncertainty,(Market Crushes).
- Its application: to the study of financial markets and financial crisis
- Also termed as statistical finance referring to its roots in statistical physics.

Tools

- Probabilistic and statistical methods taken from statistical physics
- Percolation models, chaotic models
- Mathematical theory of complexity and complex system and networks
- Information theory,
- Economic phenomena are the result of the interaction among many (hetero-) agents
- Money-energy analogy

History of Econo-physics

- Econophysics was started in the mid 1990s, coined by H. Eugene Stanley
- Driving force -the availability of huge amounts of financial data, since 1980s.
- The principle - applying statistical mechanics to economic analysis
- Since 1870 (Pareto Law) general equilibrium theory in economics based on the concept of mechanical equilibrium.

New Paradigm: Networks

2) Social@business networks => basis of stability of society

3) Electricity power network

4) Informational networks: radio,tv,e-libraries, mobile phone networks

5) Internet and www

6) Airline network

7) Bio-networks: network of neurons and so on

Mystery of the "Small World"

- Very often in very strange place, ie very far from home or from our country we met somebody who is loosely connected to us
- Somebody who has studied at the same school or knows your good friend
- Is this coincidence or Law?
- This phenomenon is called as "small world"

Discovered by Social psychologist Stanley Milgram

- Each two people in USA are connected by social path of the very small length!
- with a typical length of about six unit
- 6 “shake-hands” between most pairs of people
- He made a few experiments
- “with lost letters” with “wrong addresses”
- The lost letters have arrived in 6 steps

Actors in Hollywood are in 3 co-stars from each other

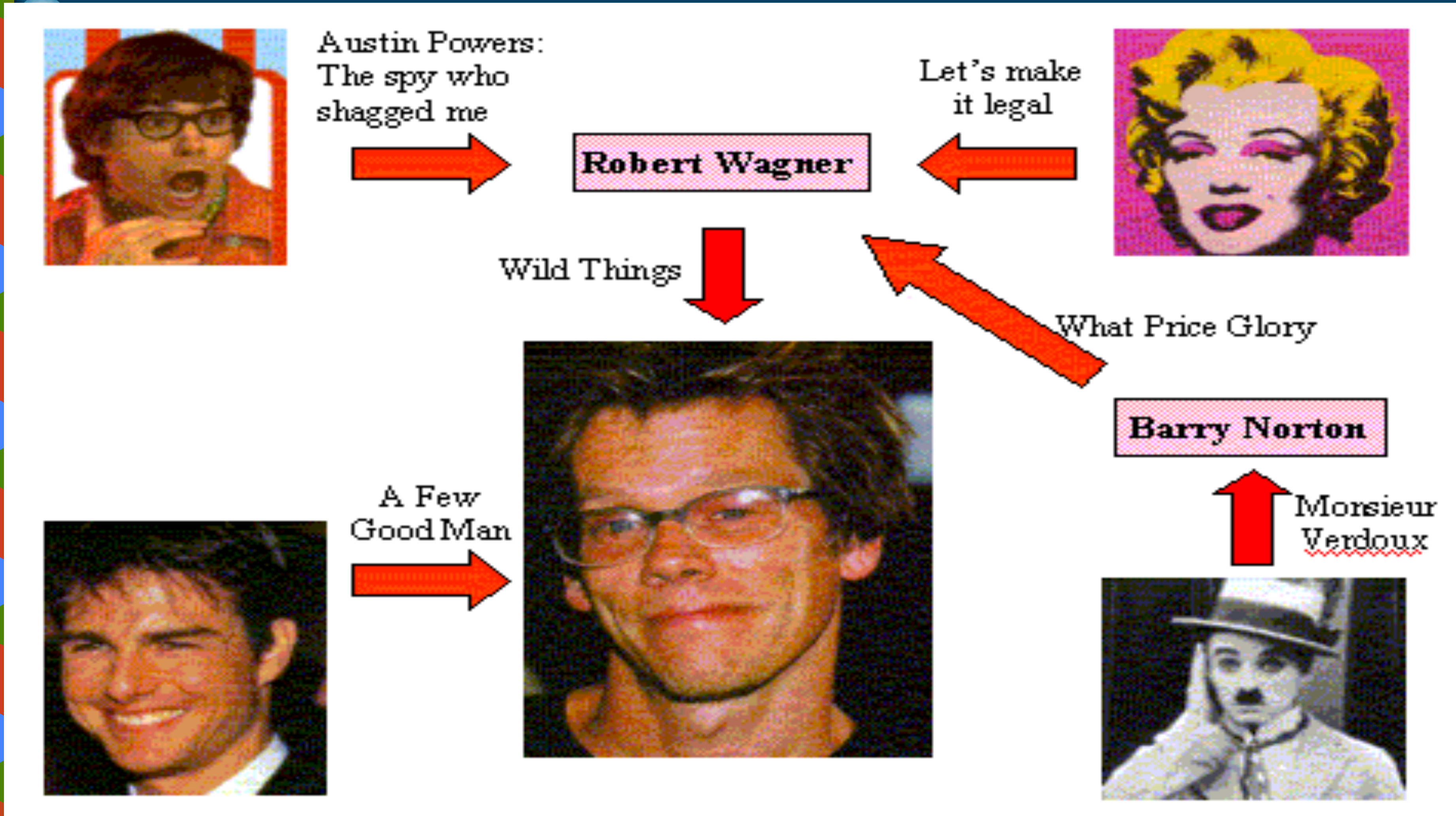
- The shake-hand or a connection when two actors are acting in the same film
- **Movie actor collaboration network**
  - Based on Internet Movie Database
  - Contain all movies and their casts since 1890

Kevin Bacon Oracle

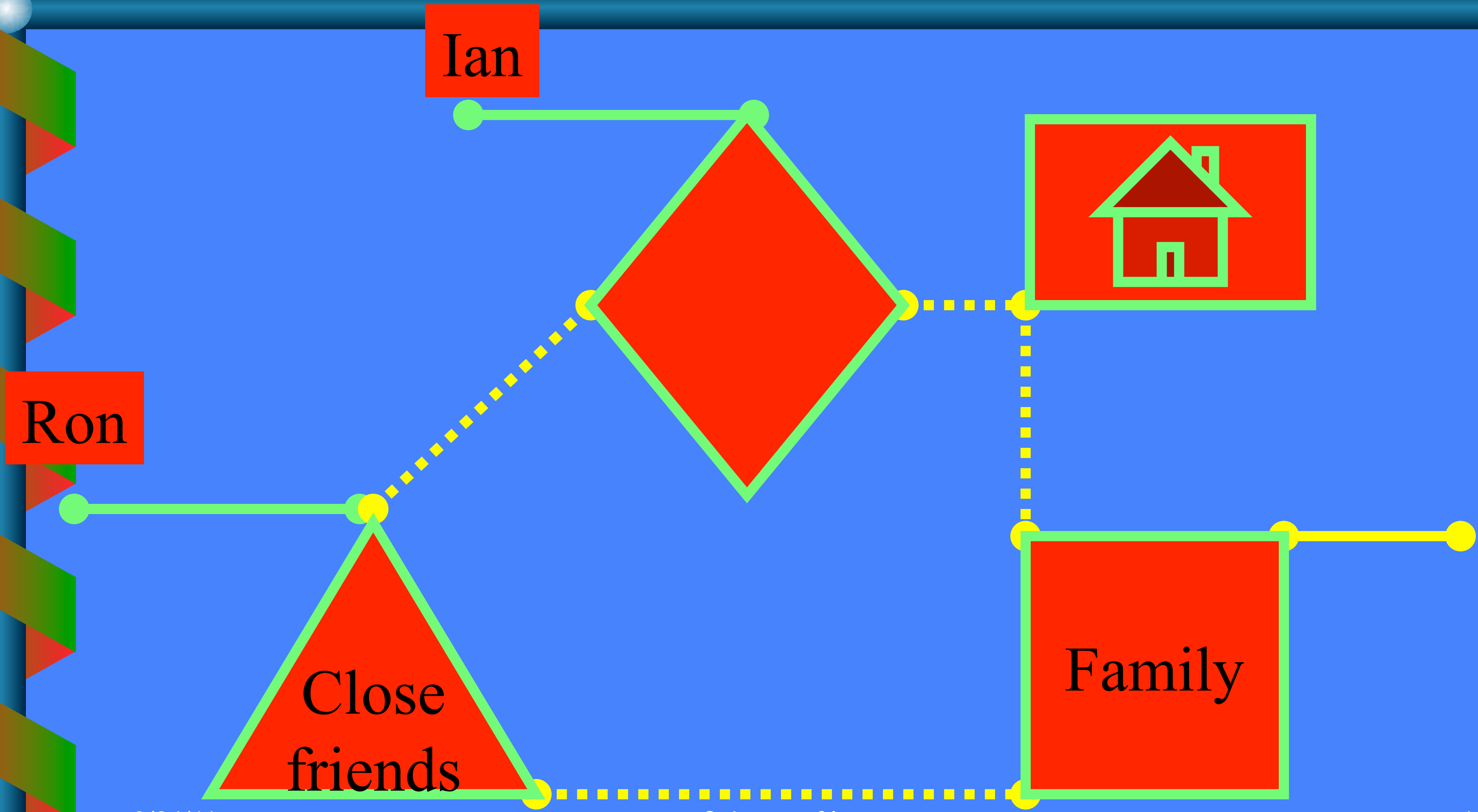
Will Smith in Independence Day (1996) with
Kevin Bacon in My Dog Skip (2000)

The Kevin Bacon game requires connecting every actor to Bacon via the movies in which they played together.

For example, Mike Myers is two links away from Bacon, as he played with Robert Wagner, who in turn played with Bacon



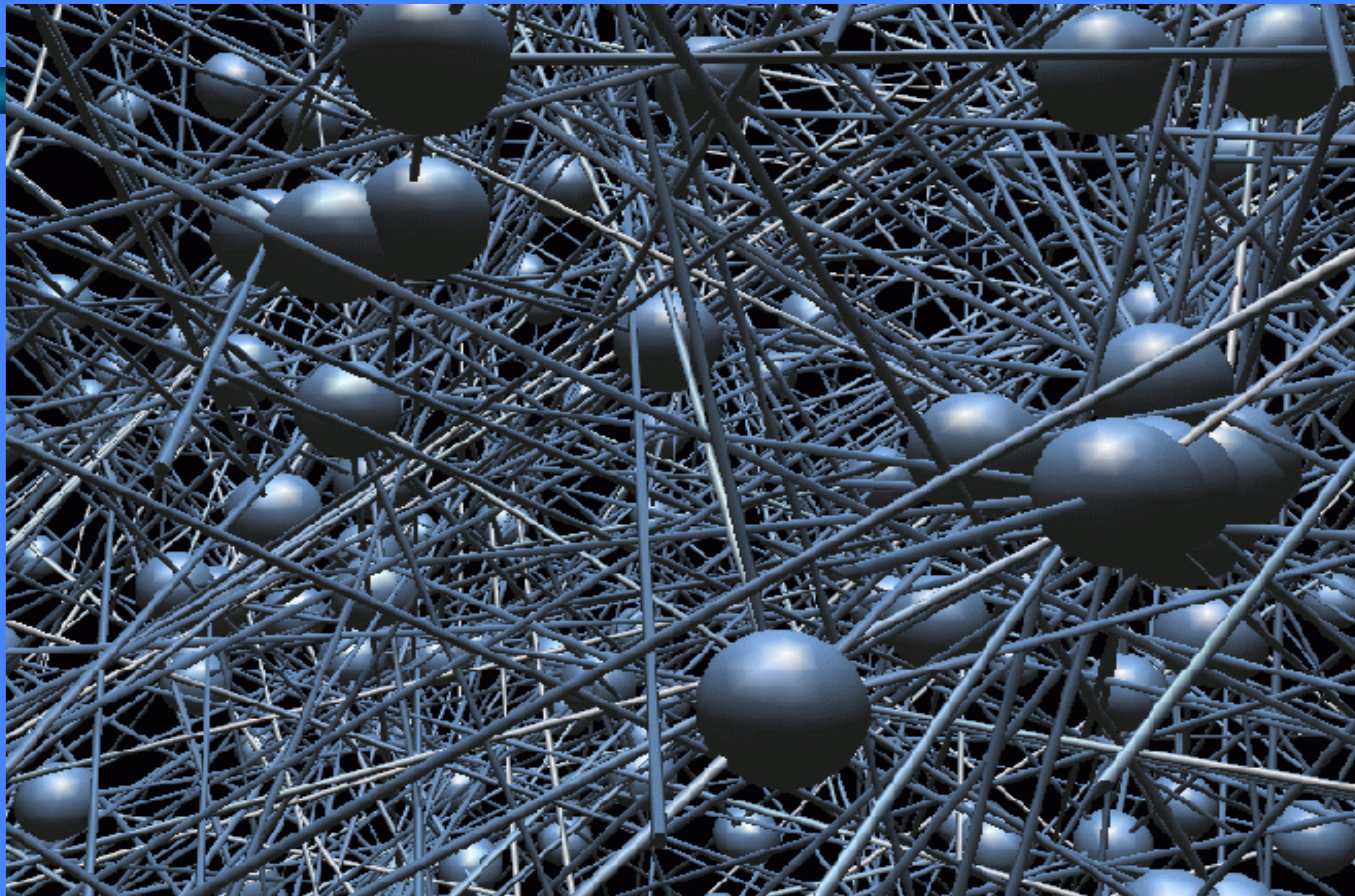
My Aunt has Strong and weak Links



Importance of weak Links

- Paradox: They are Social Glue of Society
- and they are extremely important !!!
- Exchange of information: Gossip, Fashion,...
- To find the Job, PhD place, Scholarship!!!,
- it is most important to use the weak links (discovery by Granovetter, 1983)
- Paradox: The strong links are unimportant

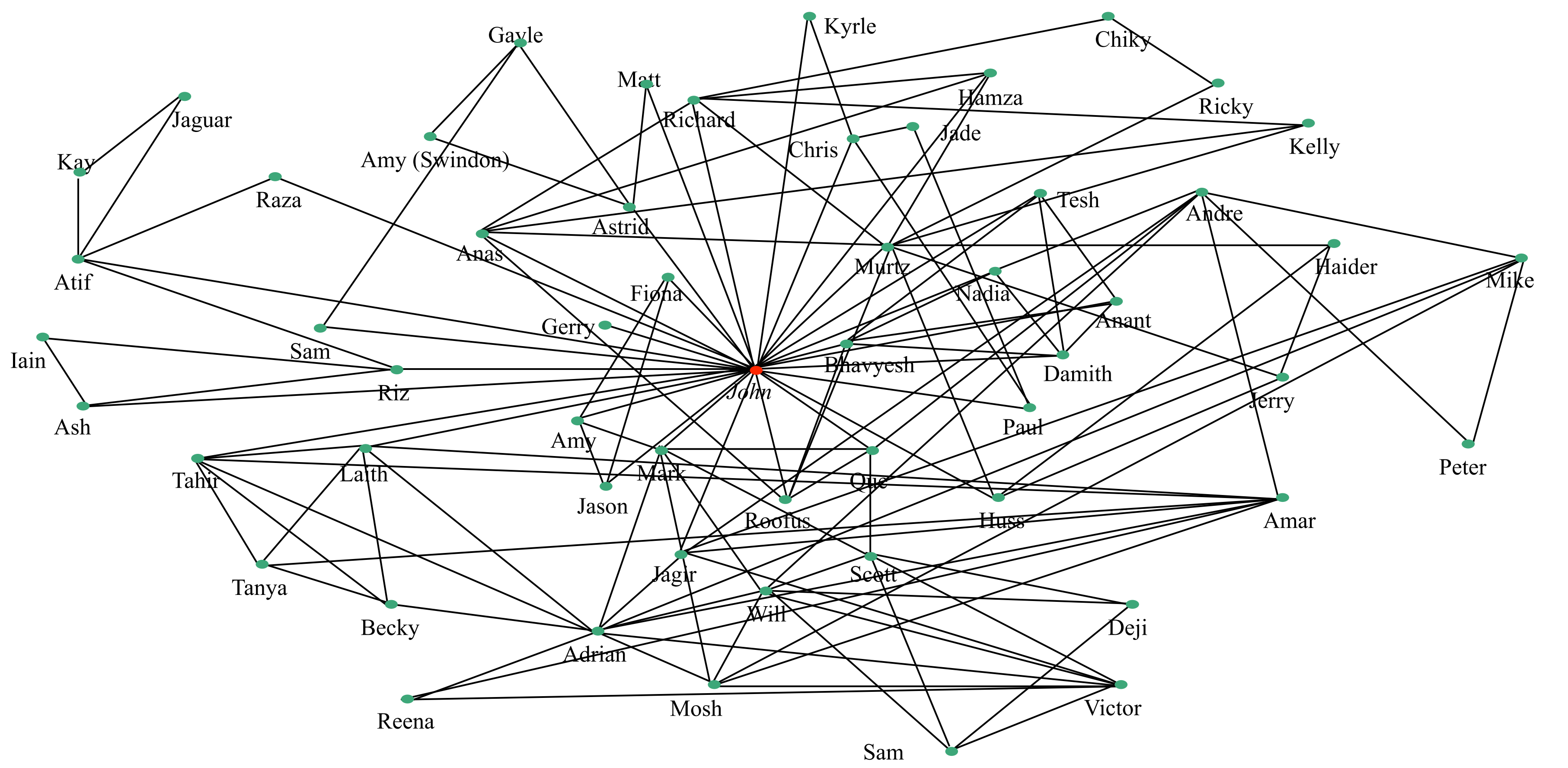
Strong and Weak Links between people in Canberra, Australia



Strong Links or How your friends' friends can affect your happiness??

- Range of phenomena are transmitted through networks of friends
  - *happiness and*
  - *depression,*
  - *obesity,*
  - *drinking and smoking habits,*
  - a taste for certain music or food,
  - apreference for online privacy,
  - even the tendency to attempt or think about suicide
  - other exciting ideas, that may change your behavior
  - ……………………………………
- Importance of the people from *three degree of separation from you*
- *We can catch the moods, habits and state of health **not only of those around us, but also those we do not even know.***

Friends with 3 degrees of separation from John has an influence on John

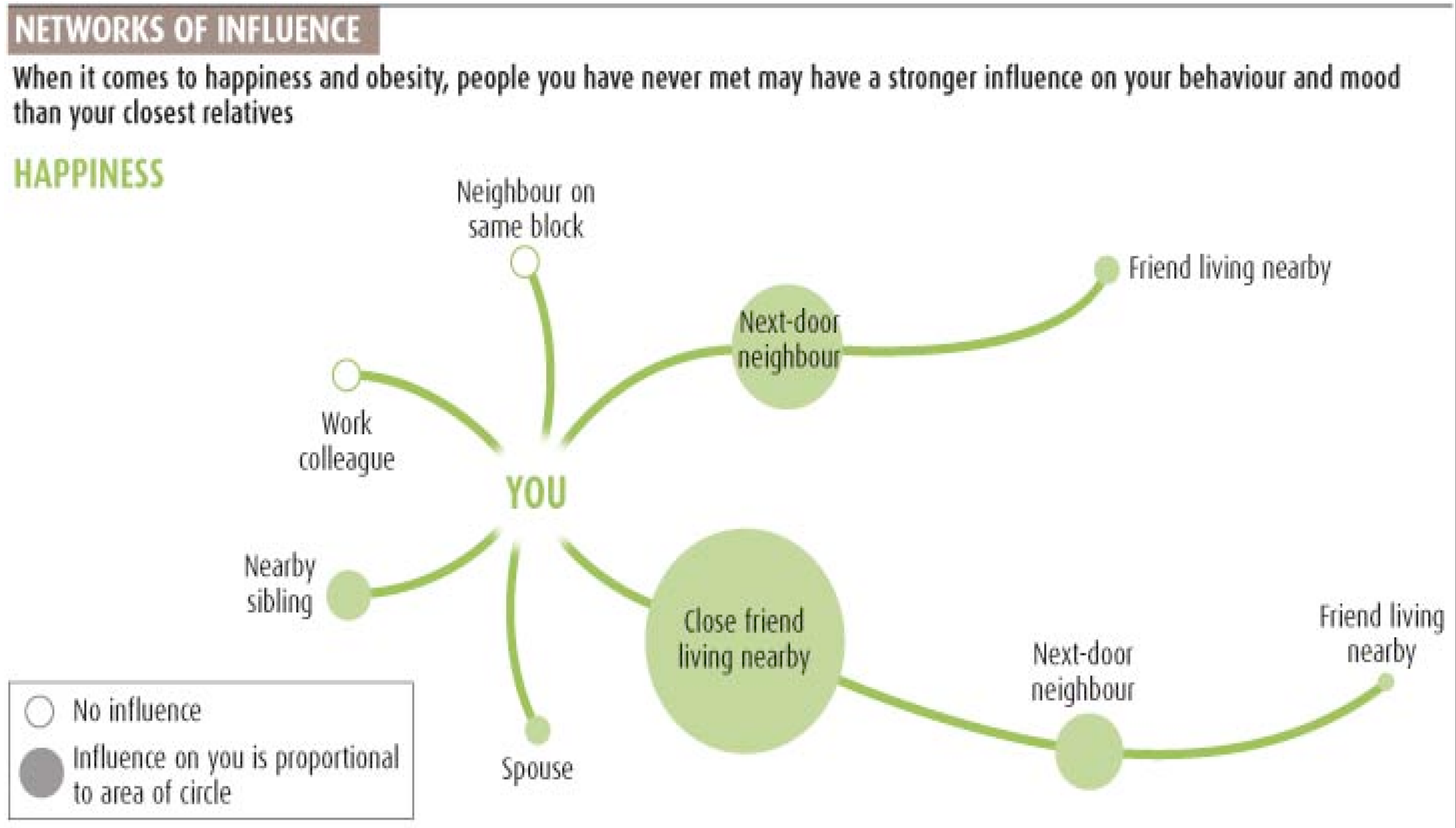


Happiness is near just find out how to get it

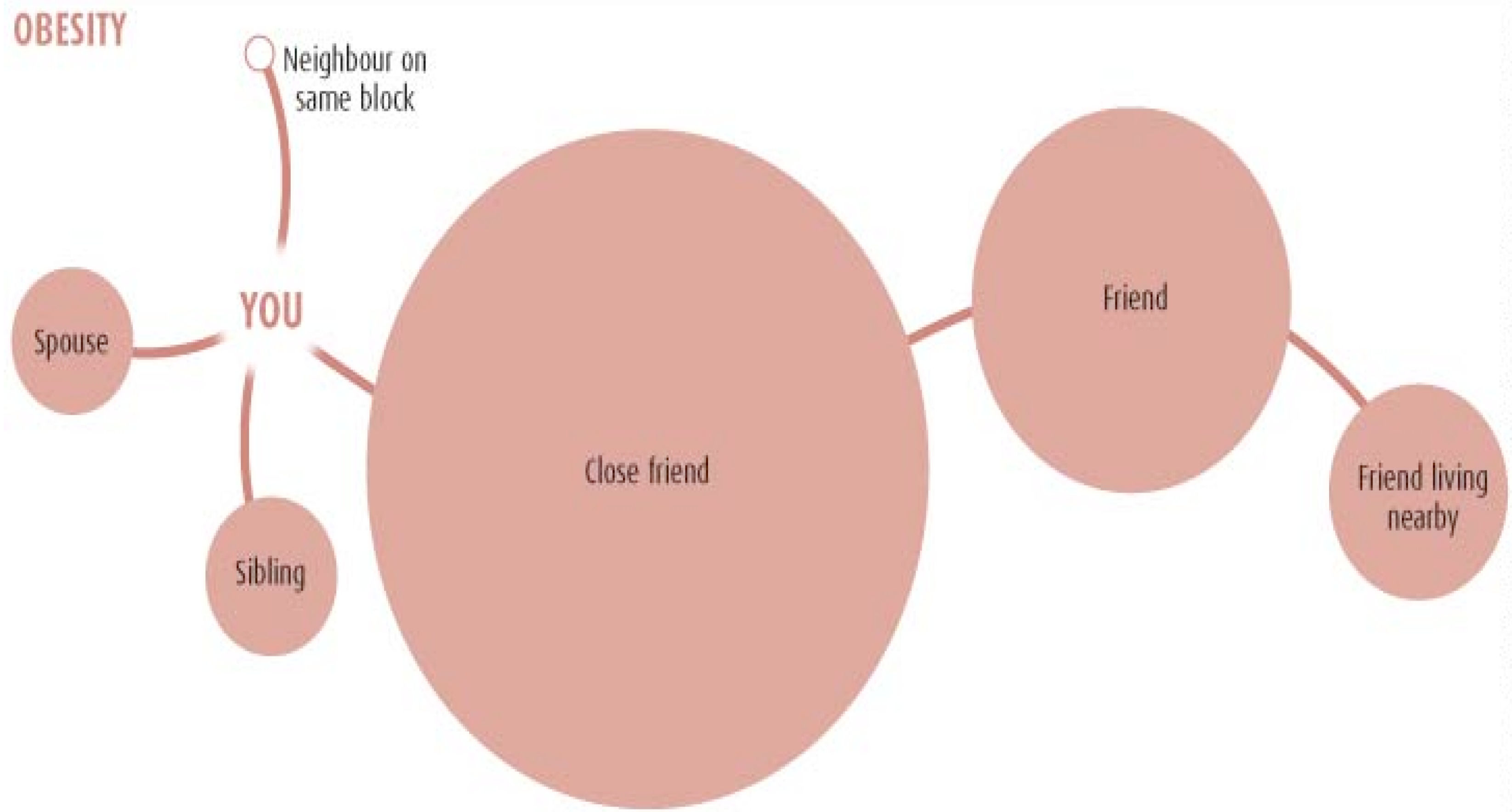
- a key question: how can something like happiness be contagious?
- people unconsciously copy
  - ➢copy manner of speech,
  - ➢posture, body language and
  - ➢other behaviors of those around them
  - ➢the facial expressions,

Actions and feelings can be as contagious as a virus

Happiness comes from friends'friends



Other habits come from friends'friends



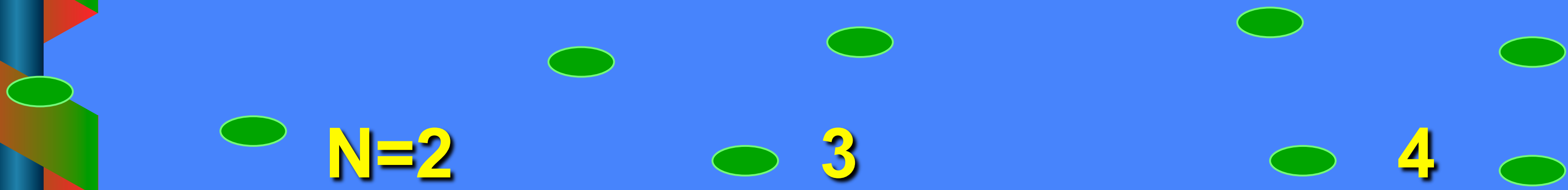
Five tips for a healthier social network of friends

- 1. Choose your friends carefully.
- 2. Choose which of your existing friends you spend the most time with. For example, hang out with people who are upbeat, or avoid couch potatoes.
- 3. Join a club whose members you would like to emulate (running, healthy cooking), and socialise with them.
- 4. If you are with people whose emotional state or behaviours you could do without, try to avoid the natural inclination to mimic their facial expressions and postures.
- 5. Be aware at all times of your susceptibility to social influence - and remember that being a social animal is mostly a good thing.

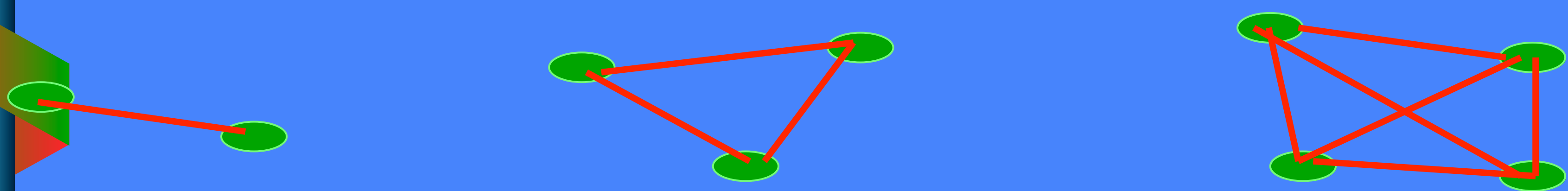
Michael Bond, New Scientist magazine, 2689, page 24-27, 30 December 2008.

Networks are typically studied with Graph Theory (Leo Euler)

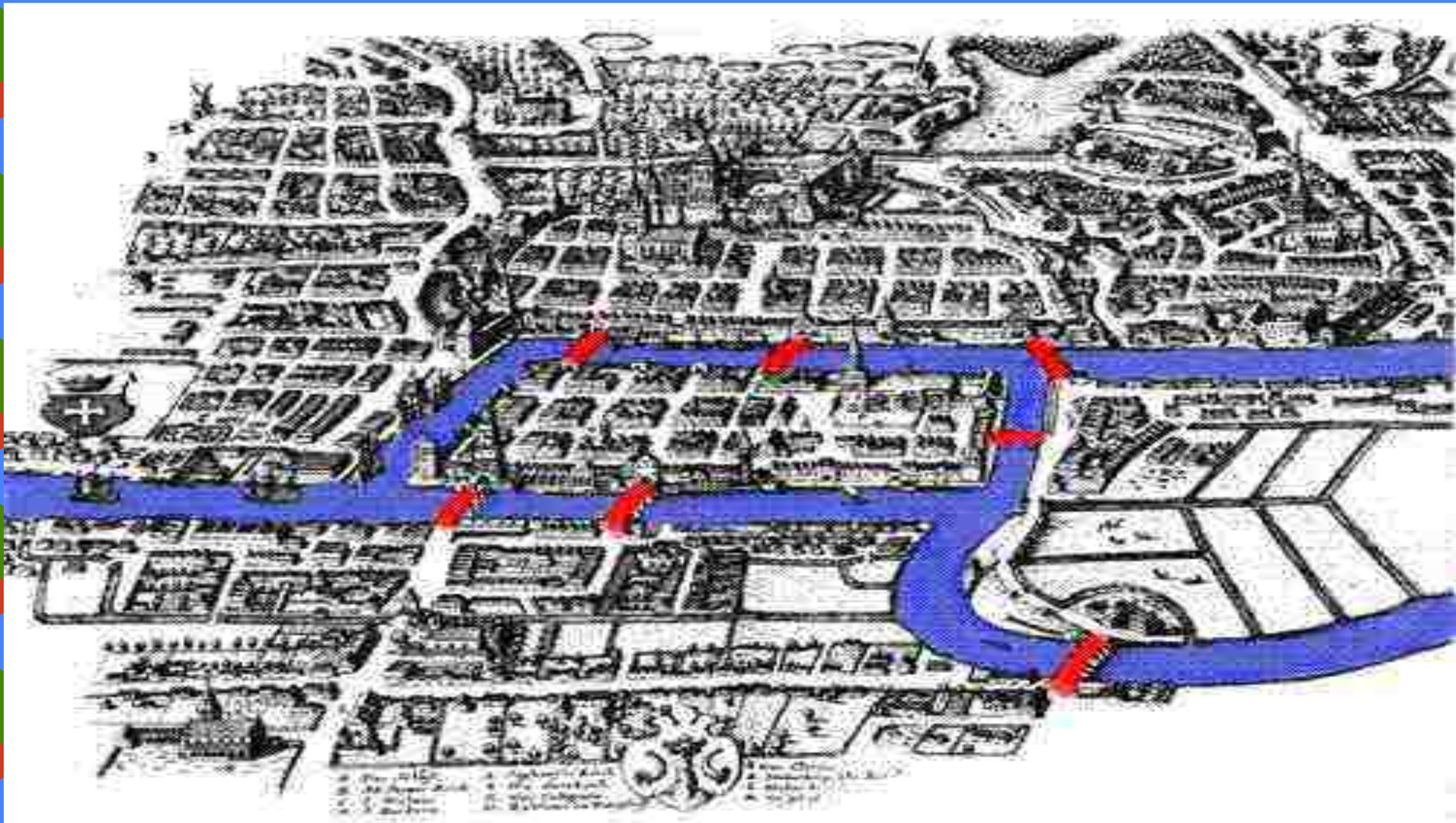
- Start with N nodes



- Nodes are connected by edges
- If each pairs of nodes are connected with edge or a link then will be created a graph with total $E_t = N(N-1)/2$ edges

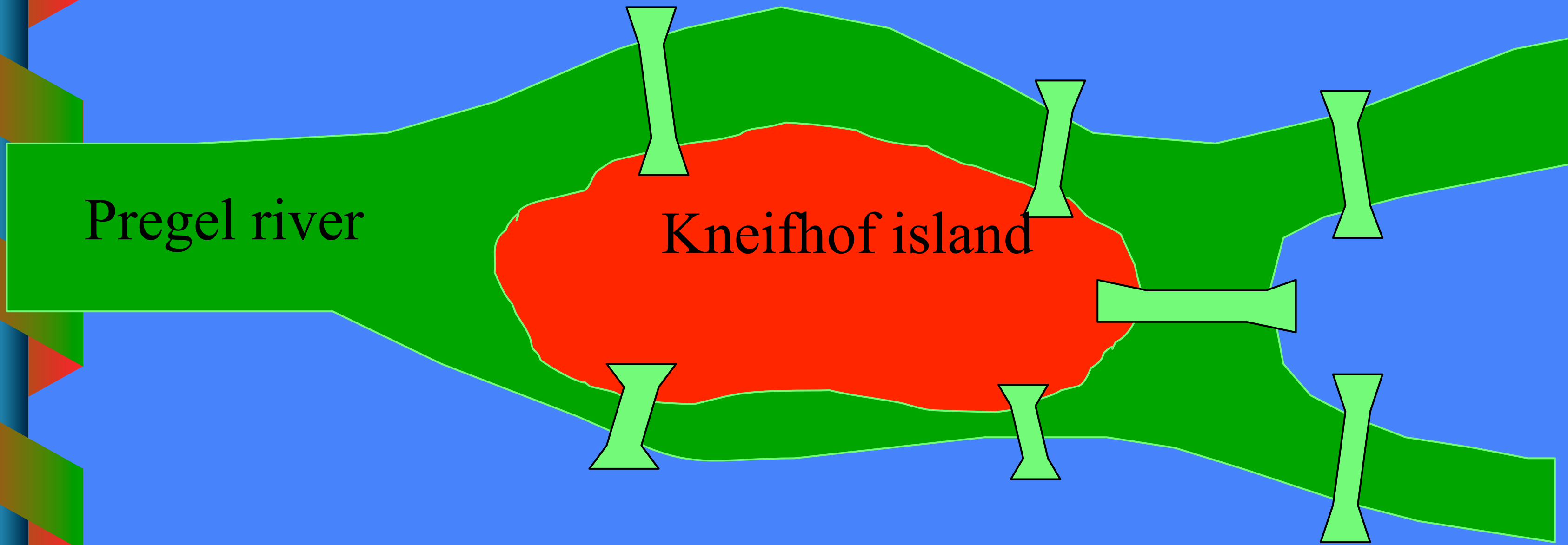


Before second world war II



Koenigsberg Problem

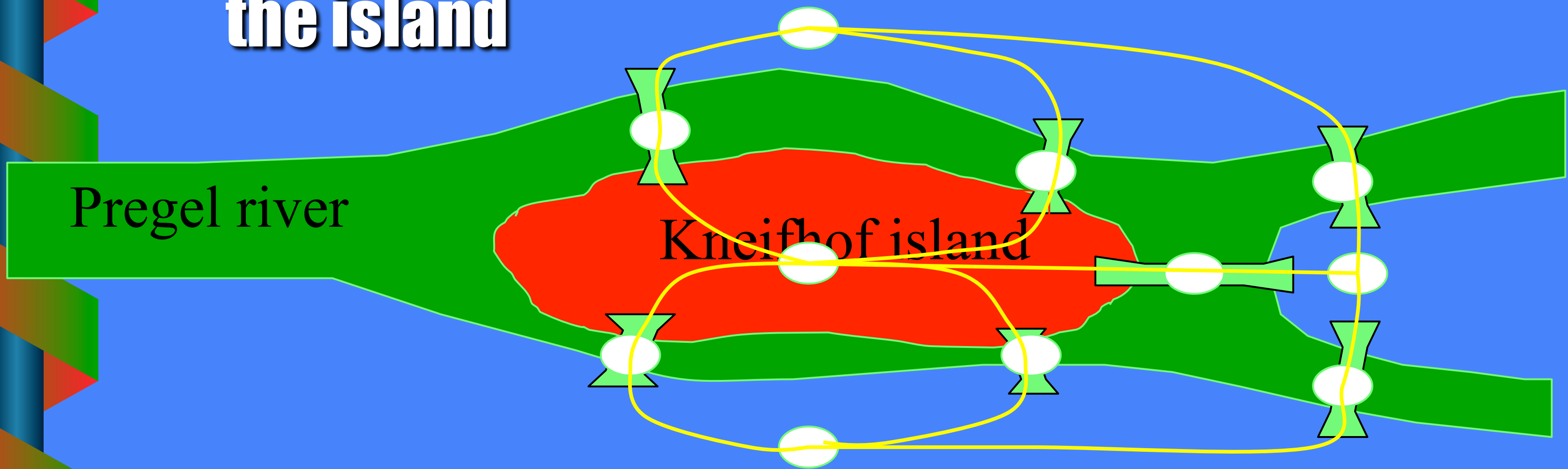
- There are Seven bridges:



- Finding a route around the city that would require a person to cross each bridge only once

Euler first introduced the idea of Graph to solve Koenigsberg puzzle

- Put nodes on the 7 bridges and on the 3 lands and the island

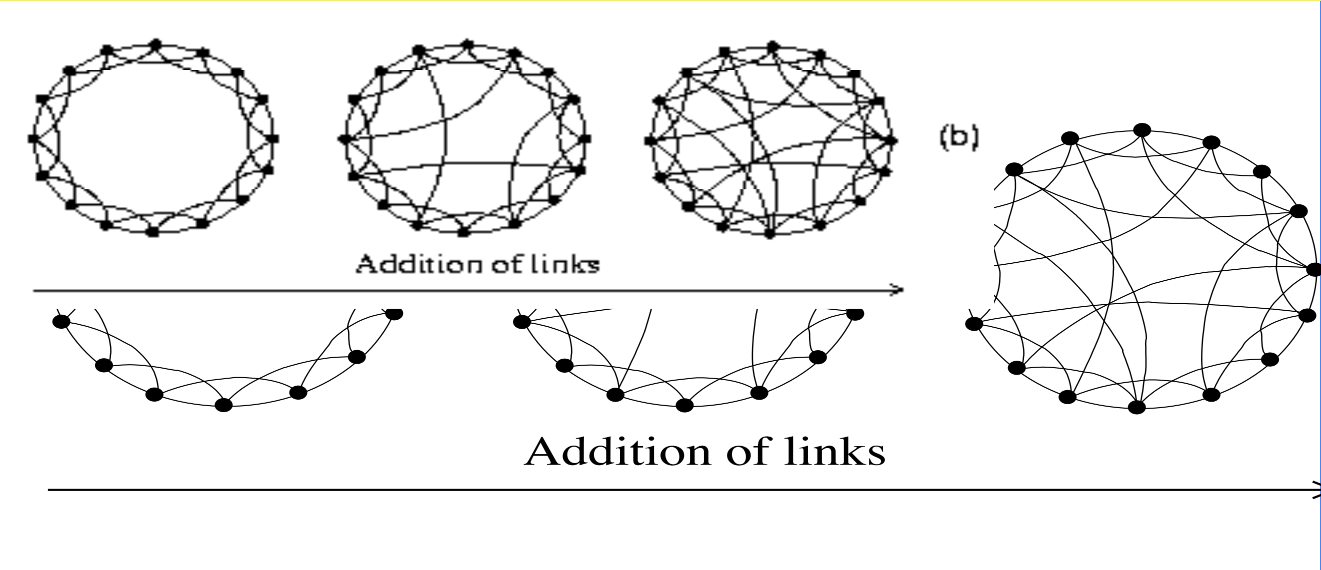


- Nodes with even and odd number of links;
- If you start from the node with odd number of links you have to return to this node

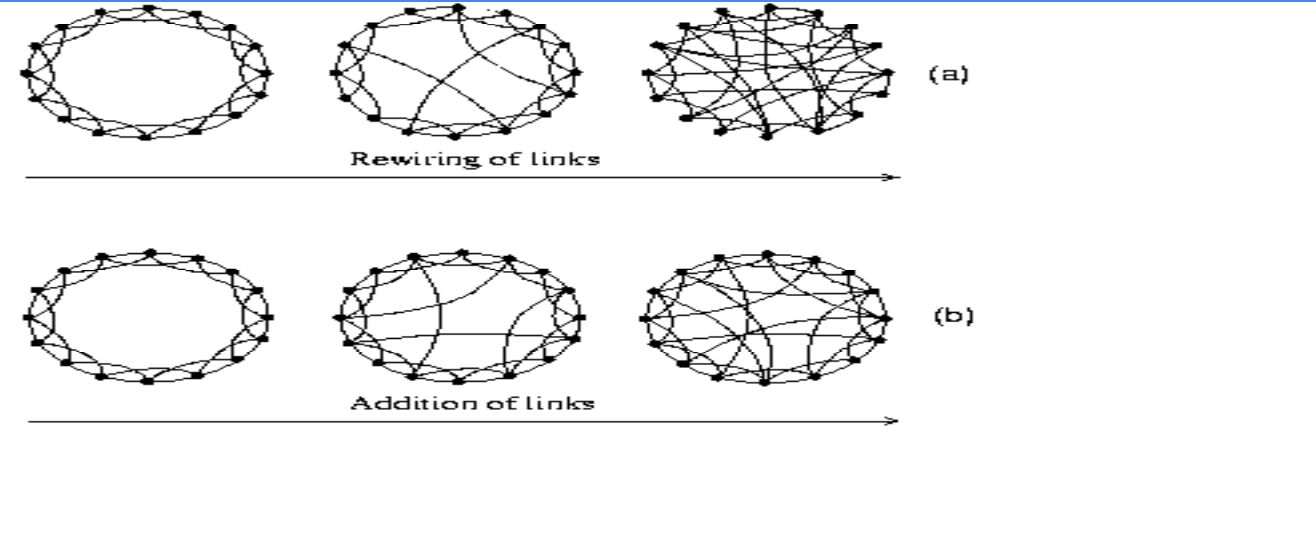
A map of Königsberg (Kaliningrad, as it is now called) after its rebuilding after its destruction in World War II

Watts and Strogatz discovery

- Started from a circle of nodes
- Each node is connected with next and next-nearest neighbours
- A few extra links are added randomly



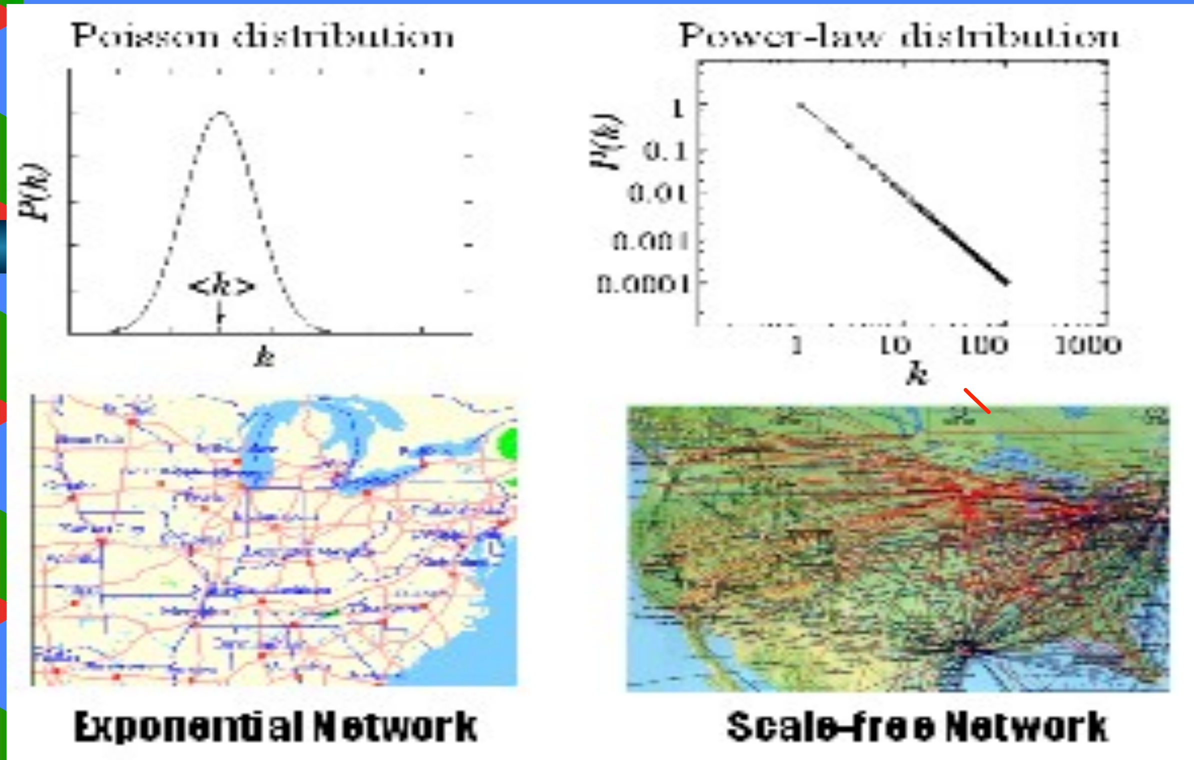
Watts and Strogatz discovery

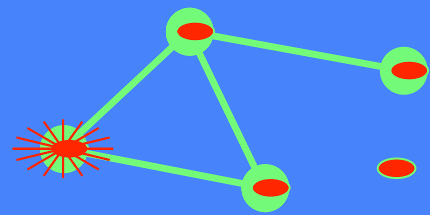


- Describe large clustering in society
- A few extra links are added randomly
- These links do not change the clustering coefficient significantly
- But make small the degree of separation between any nodes of the network

Poisson Distribution

$$P(k) = C_{N-1}^{k} p^{k} (1-p)^{N-1-k}$$





The Poisson degree distribution of a random network means that the network is similar to a highway system. In contrast, networks with a power law degree distribution (scale-free) are more similar to the airline routing map

Connectors=Hubs

Are people with many links

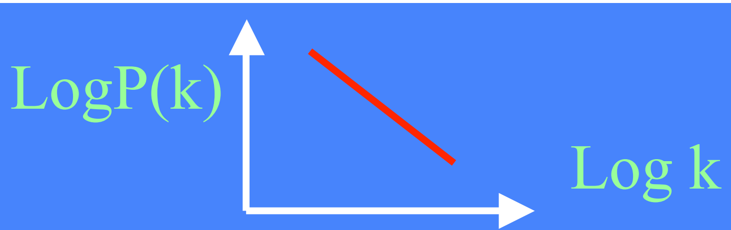
They are easily making friends and acquaintances

- They spread fashion, gossips, deceases and many trends

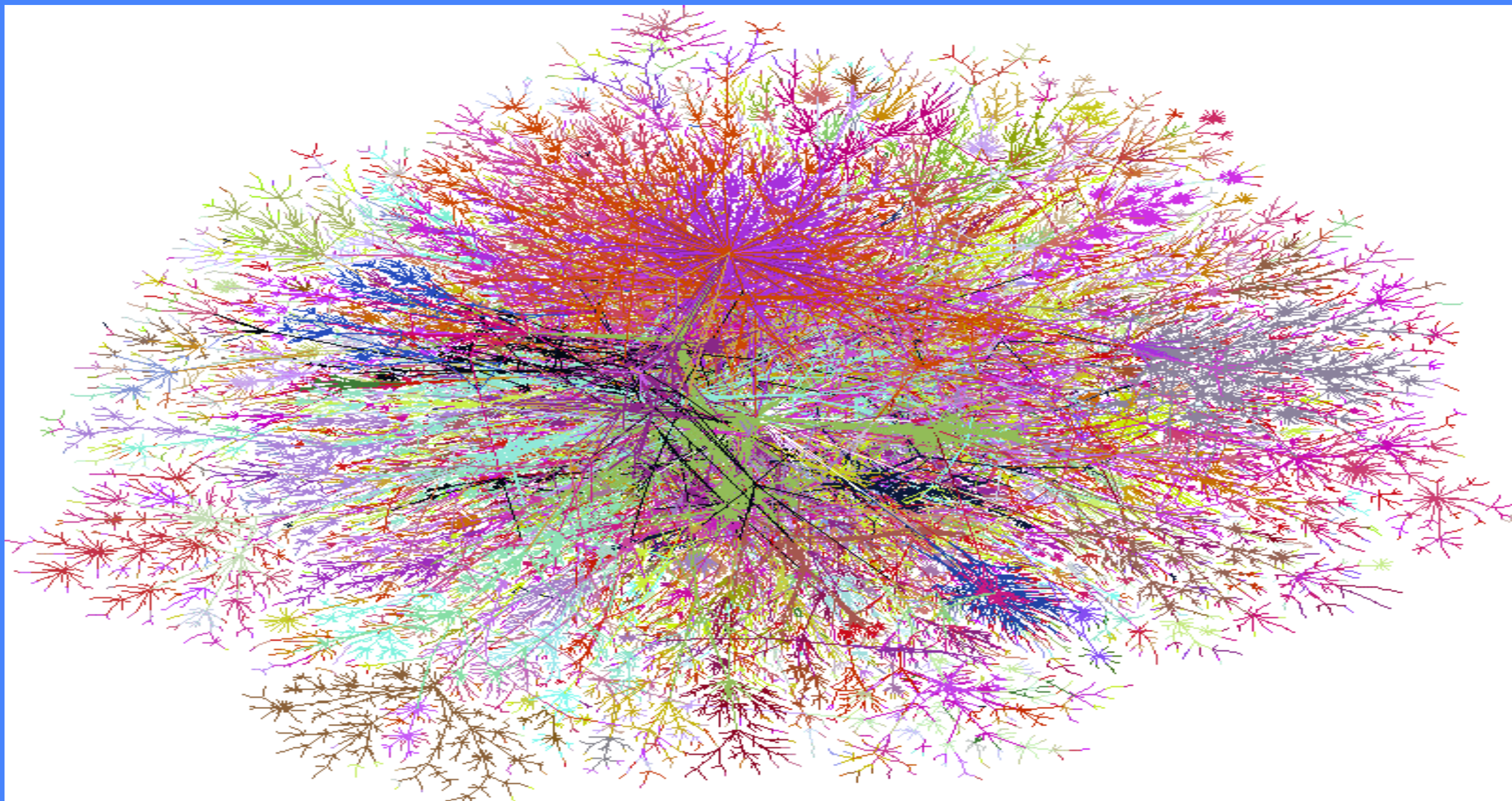
- They penetrate the society in all directions

They are extremely useful to keep the society

The connectors are fundamental property of all real networks



Small World of Internet (Map)



Fractal structure

Domain Structure of Internet

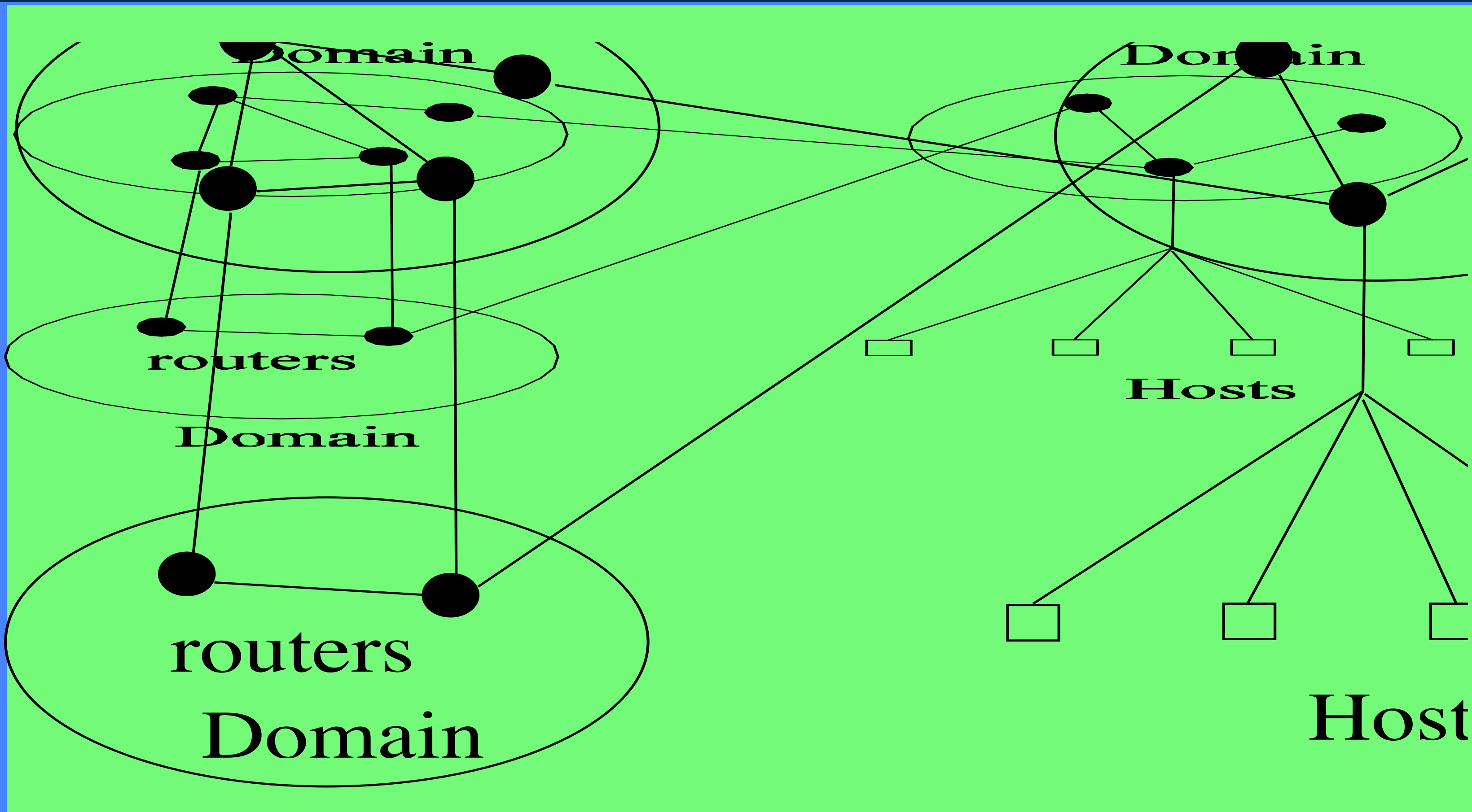
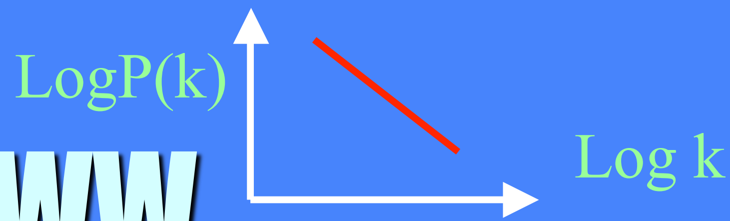


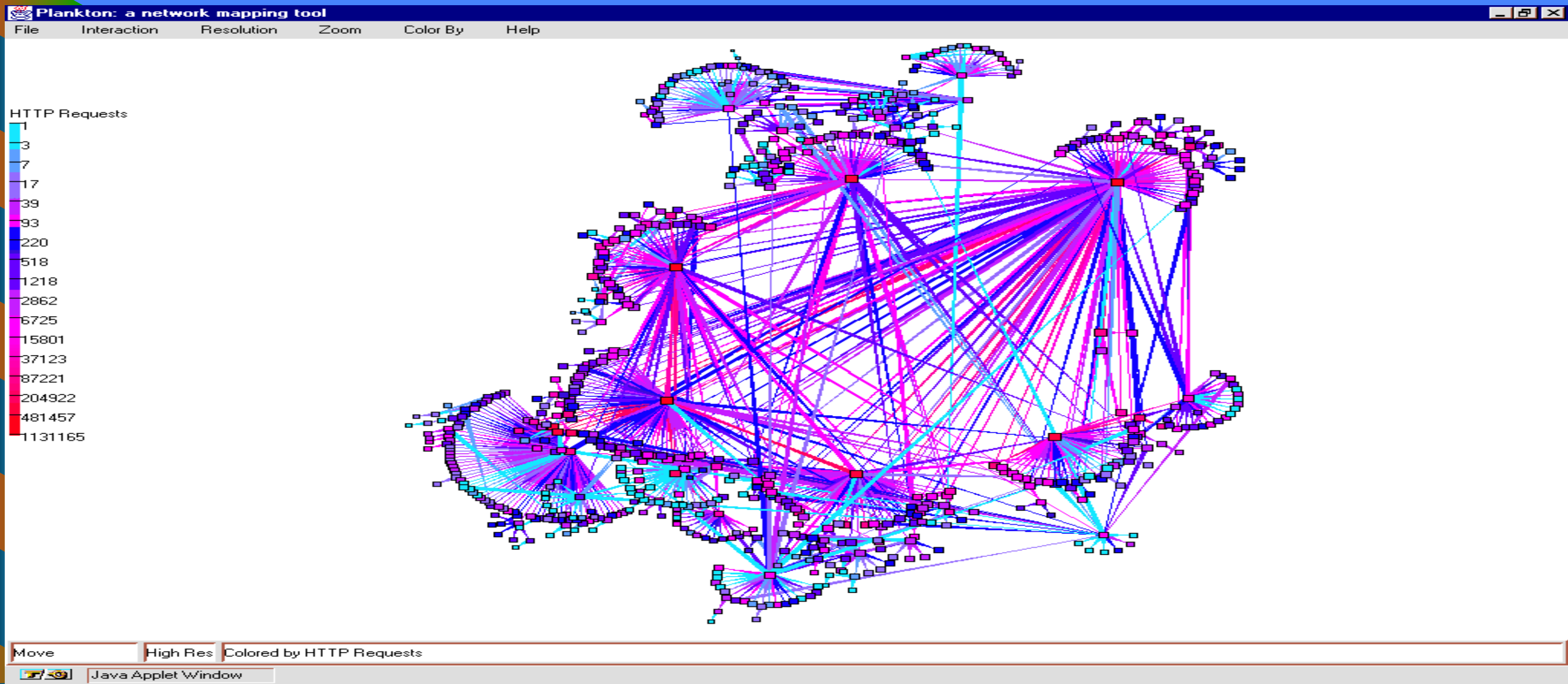
Table 3.2 *Basic parameters of the Internet graph (the interdomain level). The data are obtained from the analysis of the maps of operating autonomous systems. The parameters for the maps from November 1997 and April and December 1999 are taken from the paper of Faloutsos, Faloutsos, and Faloutsos (1999). The average values for 1997, 1998, and 1999 were obtained by Pastor-Satorras, Vázquez, and Vespignani (2001) and Vázquez, Pastor-Satorras, and Vespignani (2002). N is the total number of AS numbers, L is the total number of interconnections, $\overline{k}$ is the average degree, $\overline{\ell}$ is the average shortest-path length, C is the mean clustering coefficient, N_{new} is the number of new AS that emerged in a given year, N_{died} is the number of AS that disappeared during this year. The maps were collected since November 1997, and so the values of N_{new} and N_{died} for 1997 are actually related to the last two months of this year. Notice that the mean number of interconnections grows with time, and $\overline{\ell}$ is stable.*

	N	L	$\overline{k}$	$\overline{\ell}$	C	N_{new}	N_{died}
November 1997	3015	5156	3.42	3.76	—	—	—
Average 1997	3112	5450	3.5	3.8	0.18	309	129
April 1998	3530	6432	3.65	3.77	—	—	—
Average 1998	3834	6990	3.6	3.8	0.21	1990	887
December 1998	4389	8256	3.76	3.75	—	—	—
Average 1999	5287	10 100	3.8	3.7	0.24	3410	1713

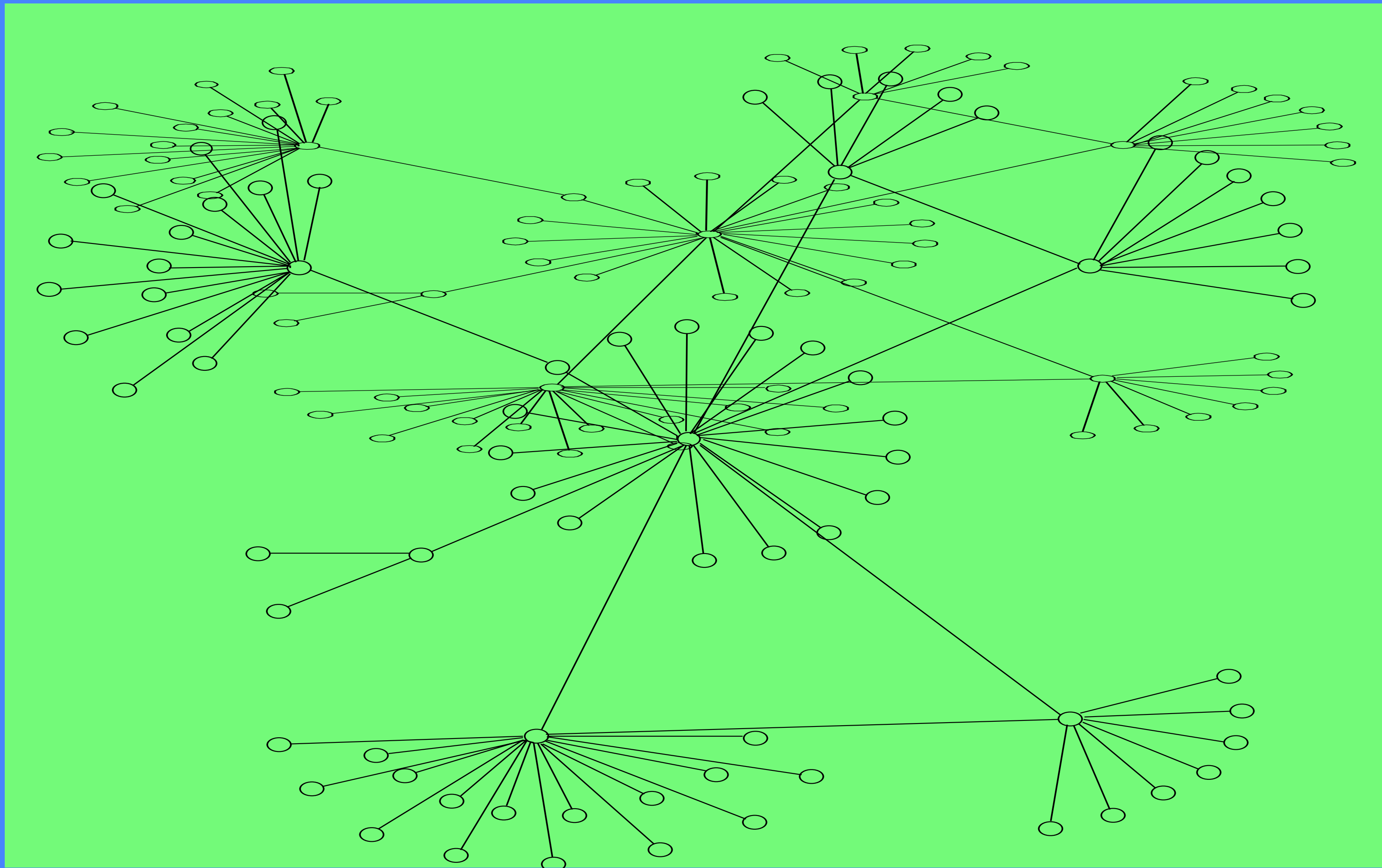


Small world of WWW

- the topology of the www- showing that webpages are on 19 clicks form each other.



Hub in the WEB



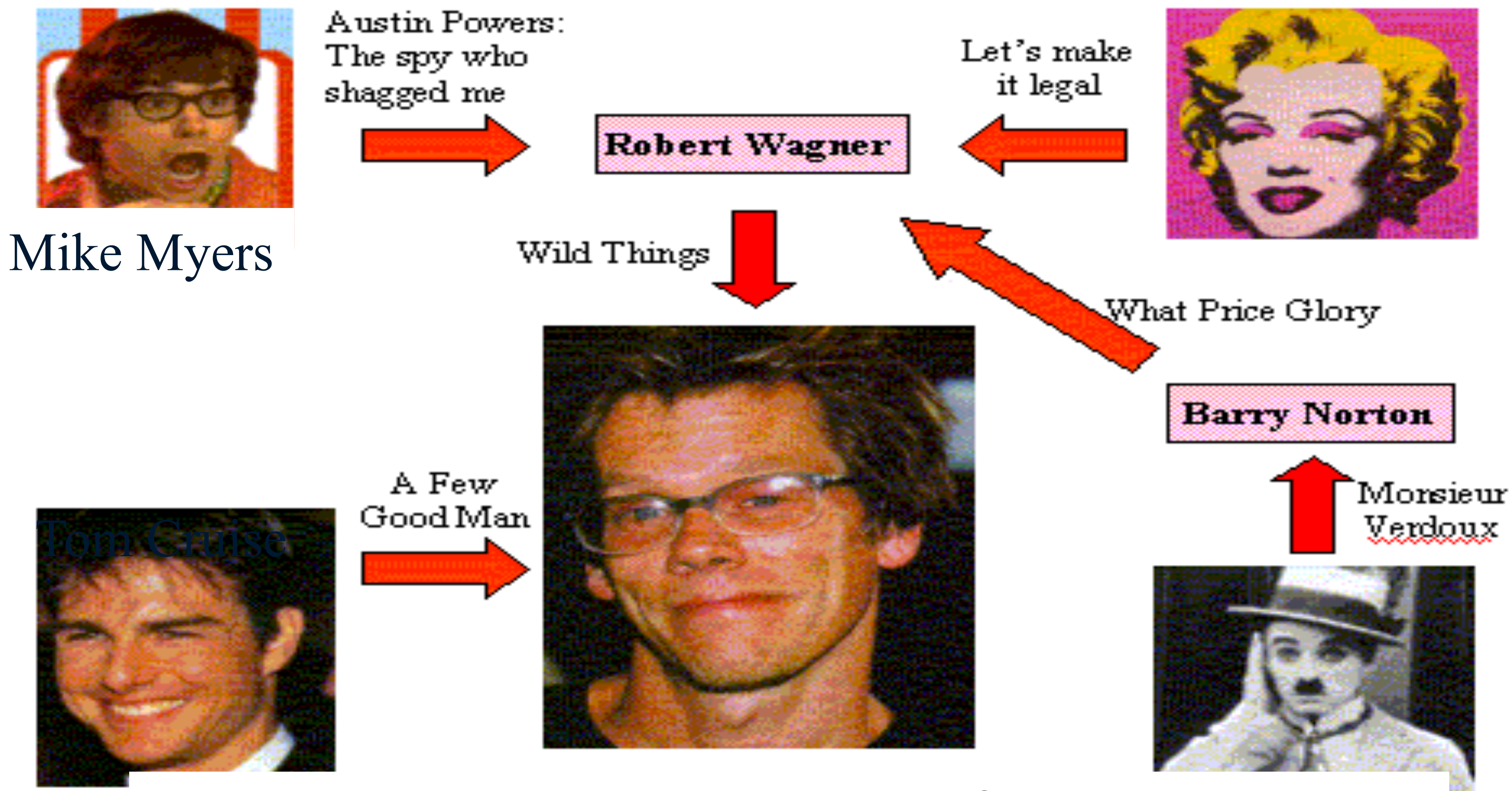
Power Law degree distribution on the WWW

Table 3.1 *The results of the fitting of the in-degree distributions for various categories of home pages in the WWW (Pennok, Flake, Lawrence, Glover, and Giles 2002). The empirical distributions are fitted by the function* $\propto (k_i + c_i)^{-\gamma_i}$*, where* c_i *is a constant. For comparison, in the two last lines the results for the entire WWW are represented: the fitting by the same dependence for the in-degree distribution, and the fitting of the out-degree distribution by the function* $\propto (k_o + c_o)^{-\gamma_o}$.

Category of home pages	γ_i	c_i
Companies	2.05	193
Newspapers	2.05	92
Universities	2.63	1370
Computer scientists	2.66	12
The WWW as a whole (in-)	2.10	0
The WWW as a whole (out-)	$\gamma_o = 2.72$	$c_o = 14$

Is Kevin Bacon a HUB or a connecter?

In the named game we were able to connect every actor to Bacon via the movies in which they played together.



For example, Mike Myers is two links away from Bacon, as he played with Robert Wagner, who in turn played with Bacon

Hubs in the movie networks: Is Kevin Bacon a HUB?

$$Connector = \frac{\# Actors}{\# films}$$

His popularity is due to a game " Oracle of Kevin Bacon"

One may assume that if the actor has acted in more films

To the more actors he should be connected

But this does not work, the size of network does not matter

Rod Steiger is an actor number one (HUB)- 2.53 links

$$Connector = \frac{\#\, Actors}{\#\, films}$$

Kevin Bacon is on 876 place, he has 2.79 links to all other actors

Rank	Name
1	Rod Steiger
2	Donald Pleasence
3	Martin Sheen
4	Christopher Lee
5	Robert Mitchum
6	Charlton Heston
7	Eddie Albert
8	Robert Vaughn
9	Donald Sutherland
10	John Gielgud
11	Anthony Quinn
12	James Earl Jones

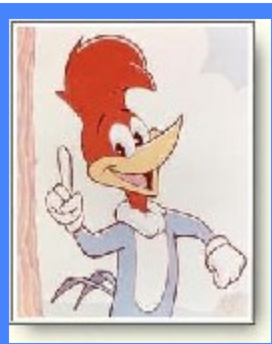
There are Hubs everywhere

Theodore Roosevelt, on of the biggest social hubs of his time, with over 22,000 acquitances.

His appointment book listed more than 20,000 people who wanted to talk to him

http://www.cnn.com/SPECIALS/1999/panama.canal/stories/history/link.theodore.roosevelt.jpg

Top Actors-Hubs

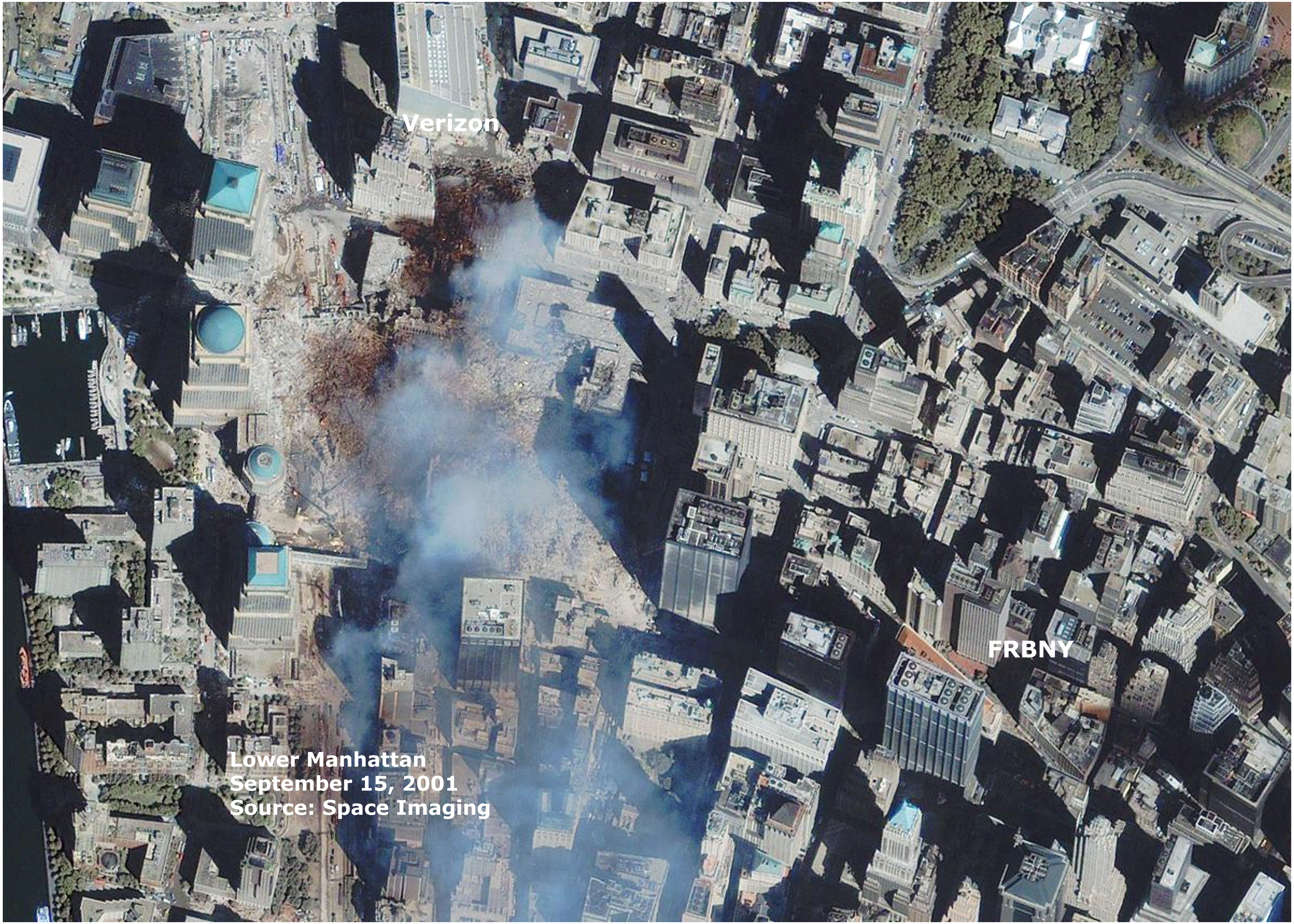


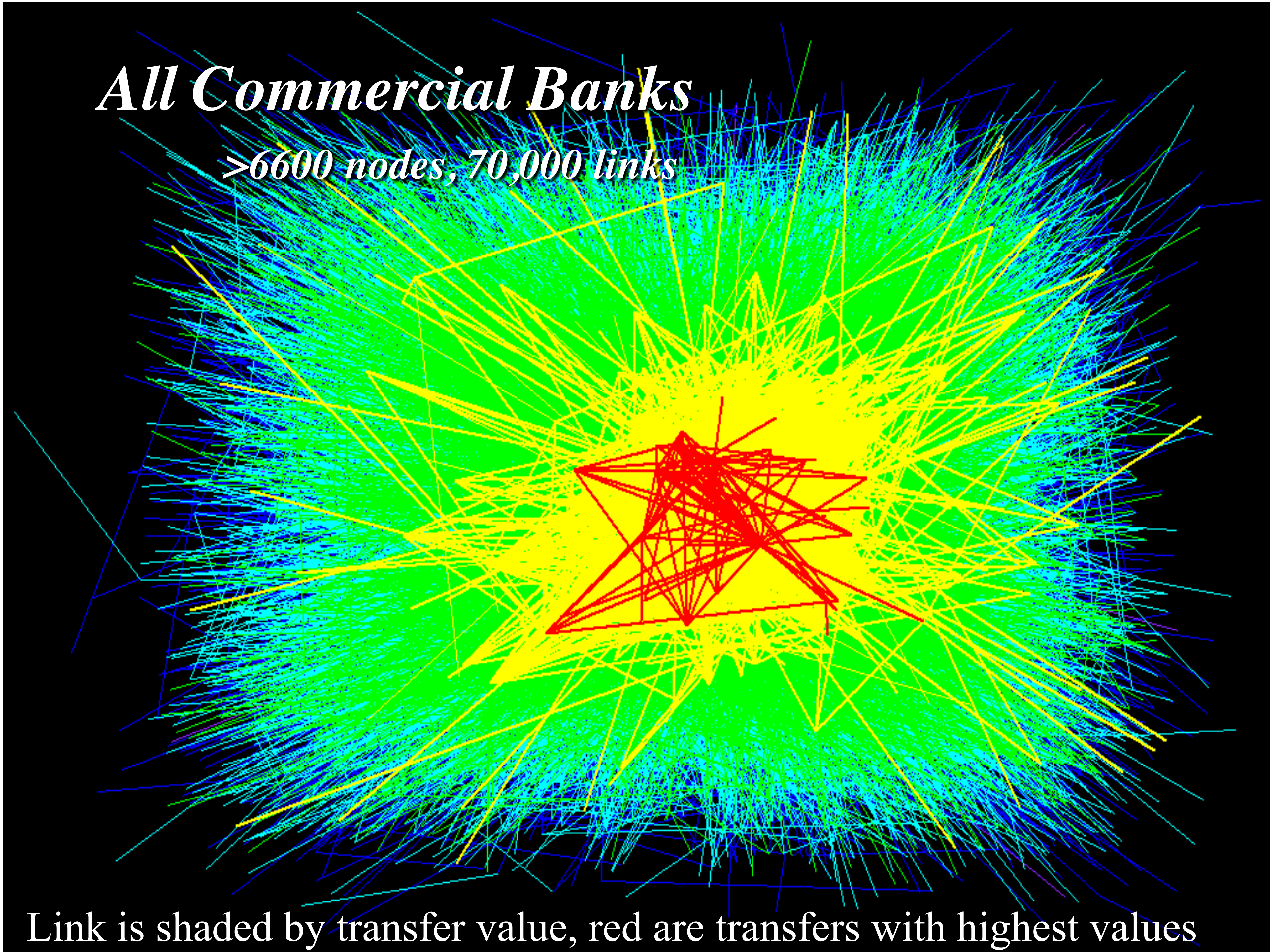
Mel Blanc
The famous voice actor, that appears in most (759) movies. He lended his voice to such characters as Bugs Bunny or Woody Woodpecker.

Spider Man, who appears in over 1600 comic books is one of the hubs of the Marvel Universe.
See, e.g. http://xxx.lanl.gov/abs/cond-mat/0202174.

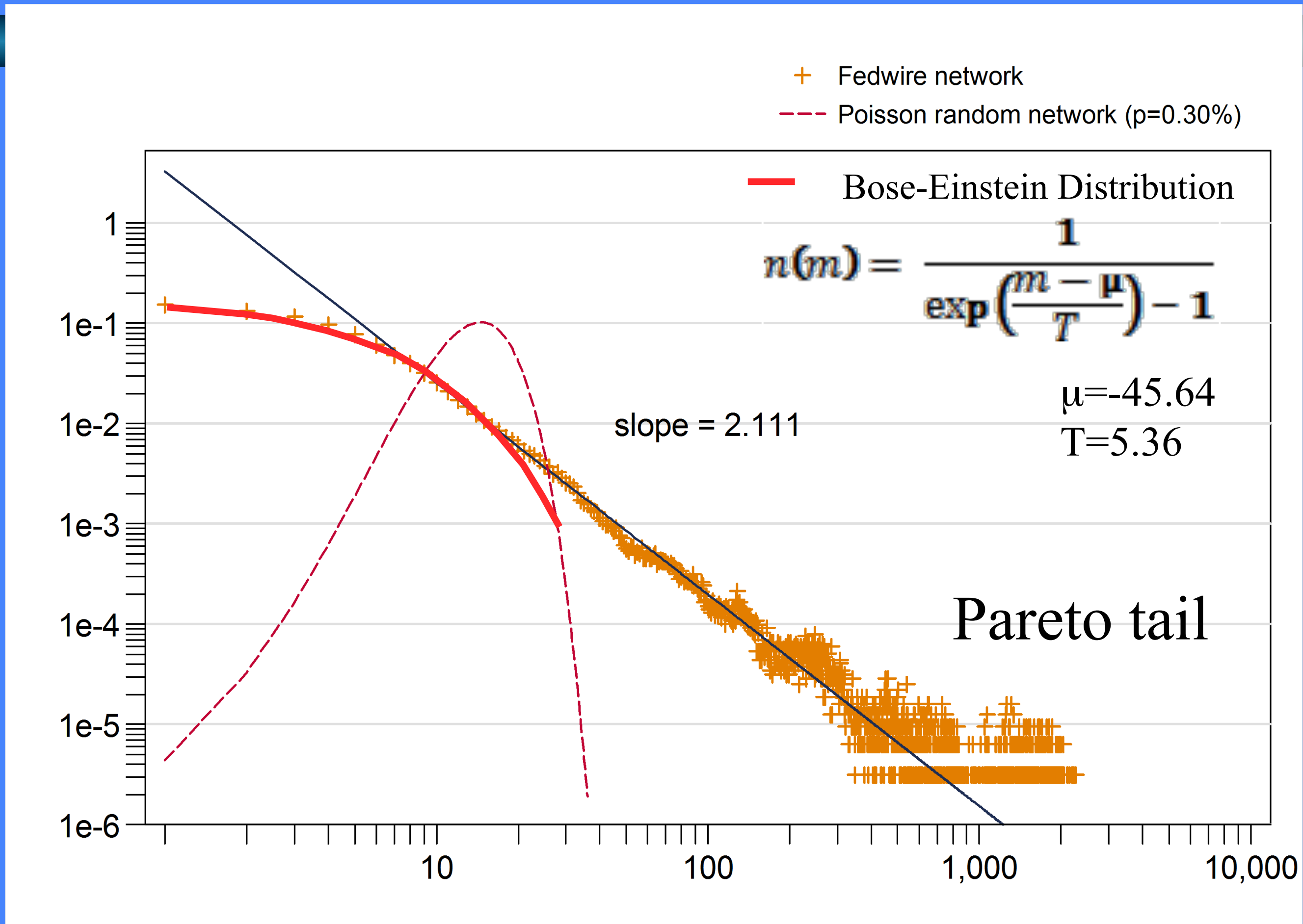
Financial network: Fedwires Funds Service- bank of banks

- Tightly connected core of banks to which most other banks connect
- Each day a new network of payments
- Properties of the network changed after events of September 11, 2001.


Verizon
FRBNY
Lower Manhattan
September 15, 2001
Source: Space Imaging


All Commercial Banks
>6600 nodes, 70,000 links
Link is shaded by transfer value, red are transfers with highest values

Out-Degree Distribution



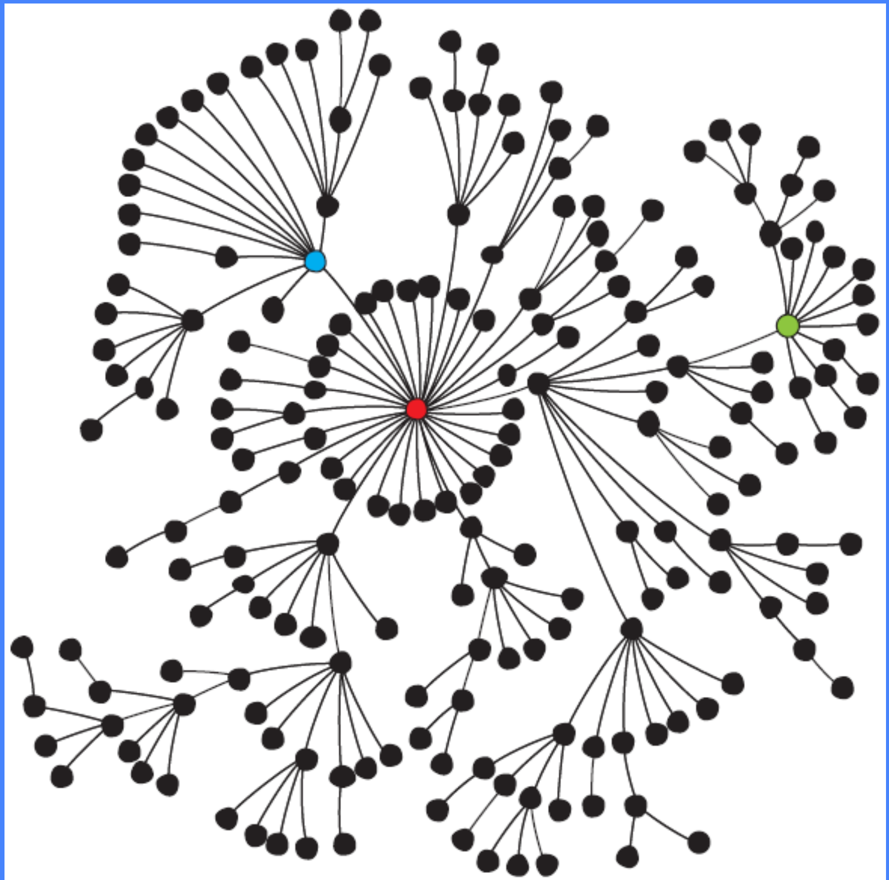
P

$P(k) \sim k^{-s}$

Degree k

Scale-free Networks

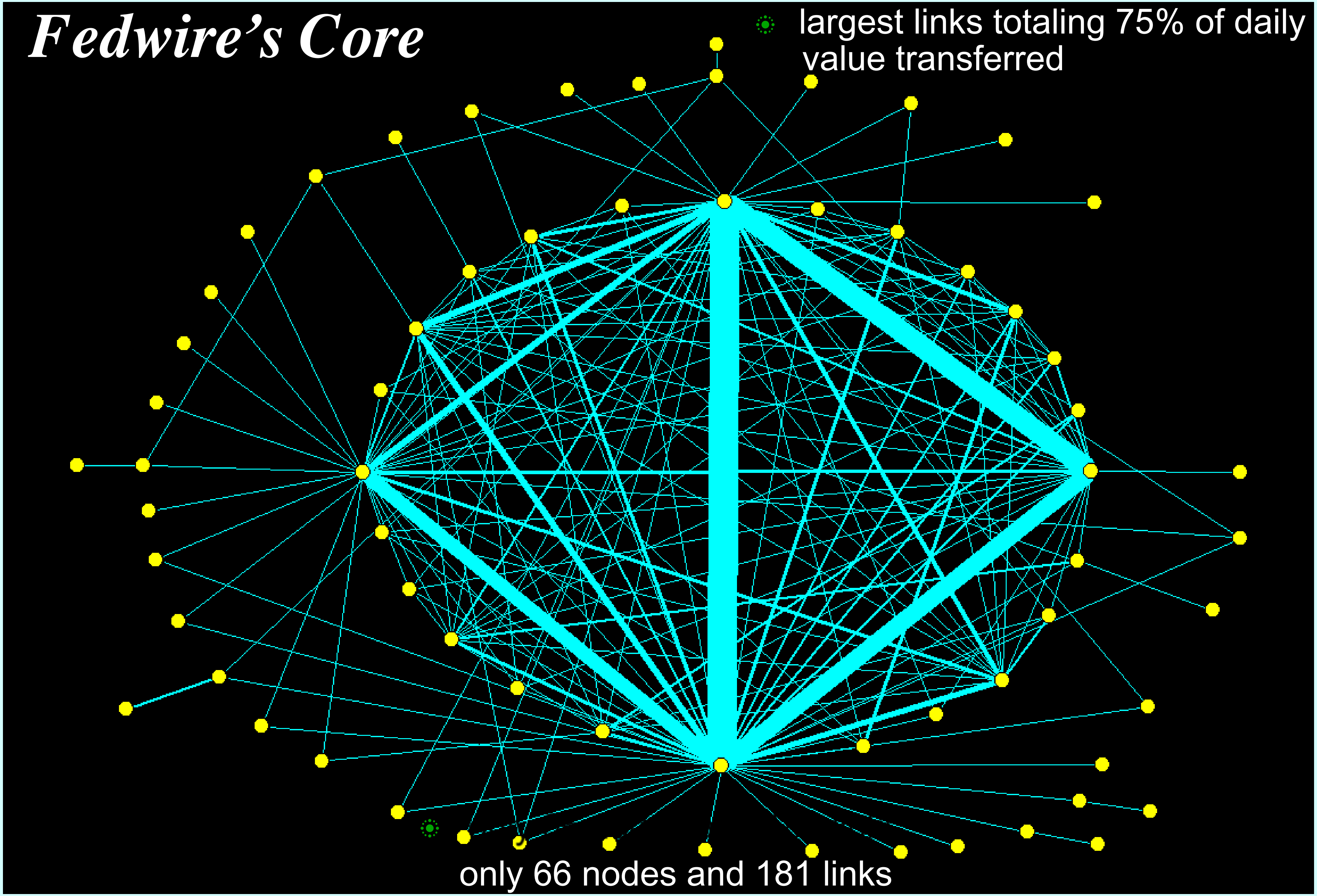
Albert, Jeong, Barabasi, Nature 2000



Preferential attachment
"rich get richer"

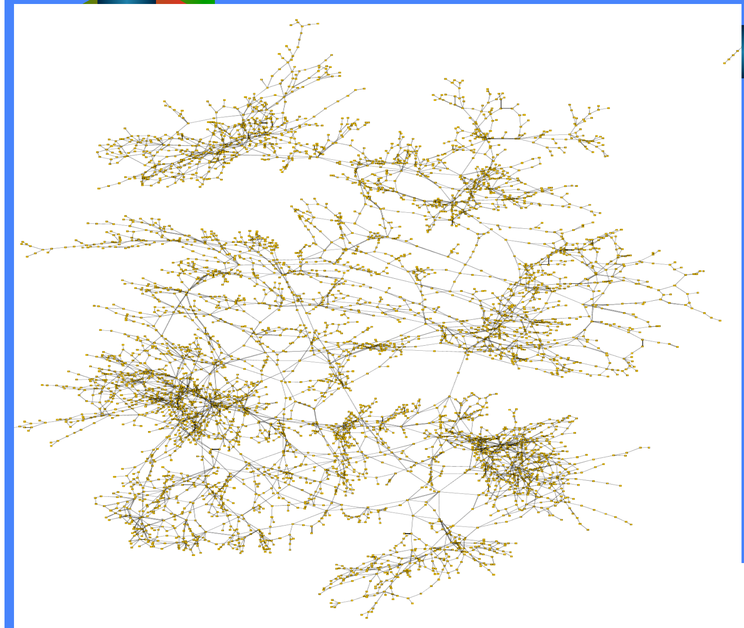
tolerant to random failure…

vulnerable to informed attack



Fedwire's Core
largest links totaling 75% of daily value transferred
only 66 nodes and 181 links

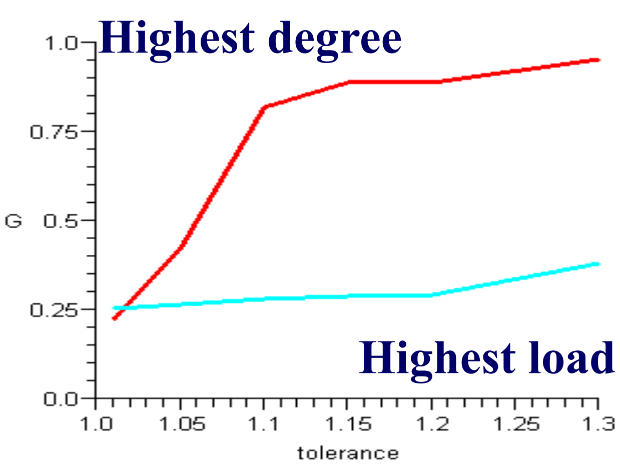
Congestive failure of the WECC



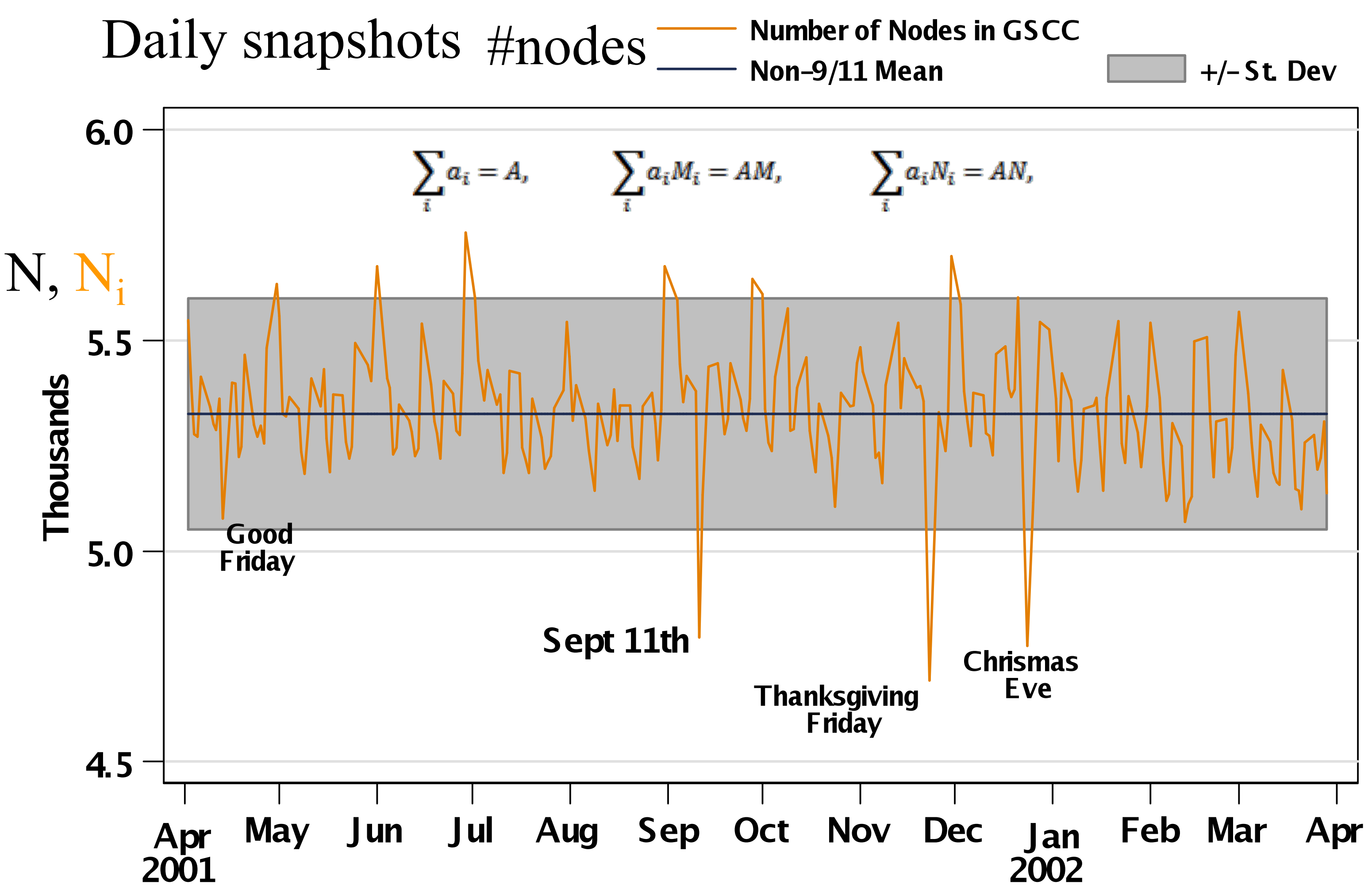
Western Power Grid (WECC), 69 kev lines and above

Power-low or fat-tailed distribution

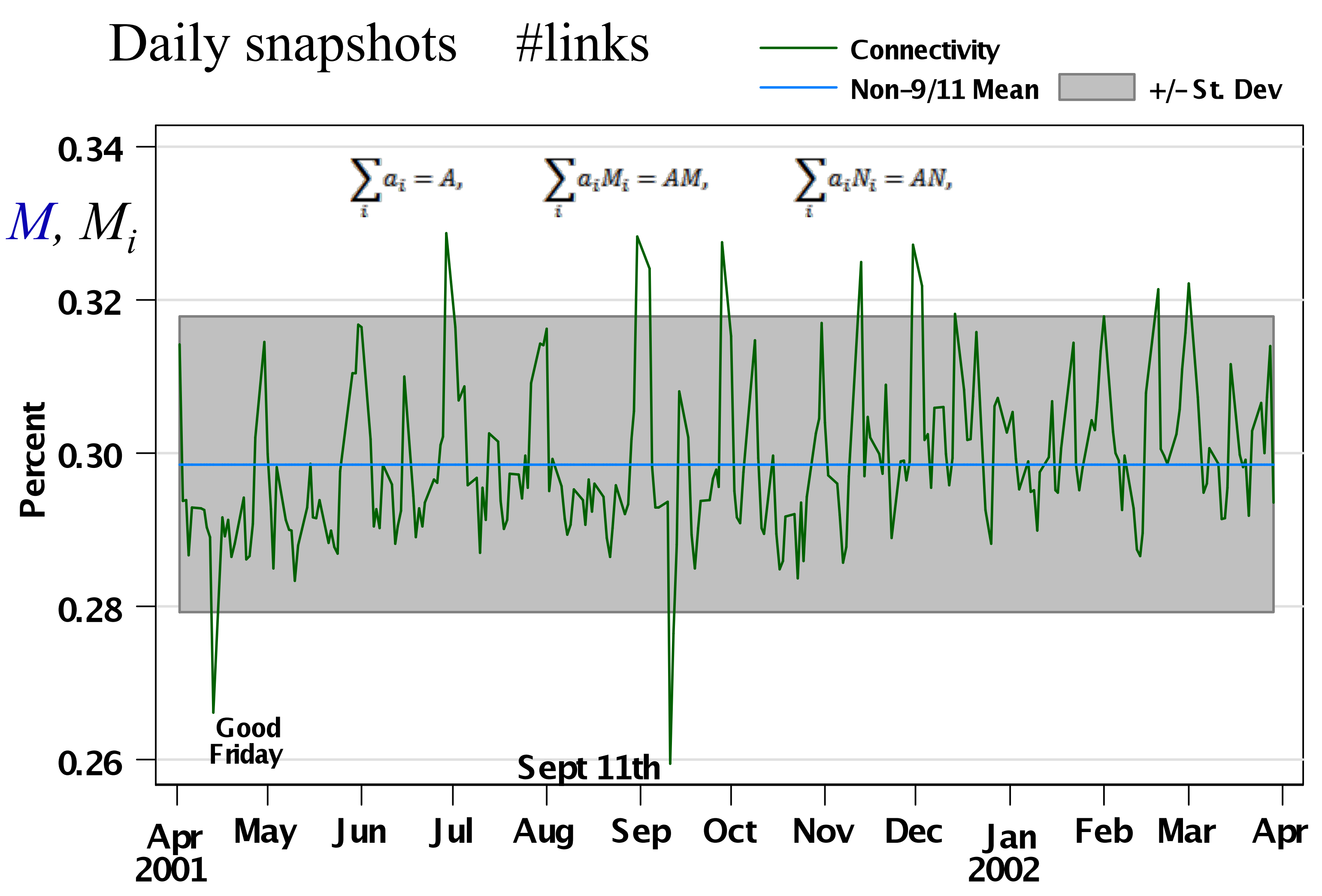
$$P(k) \sim k^{-s}$$



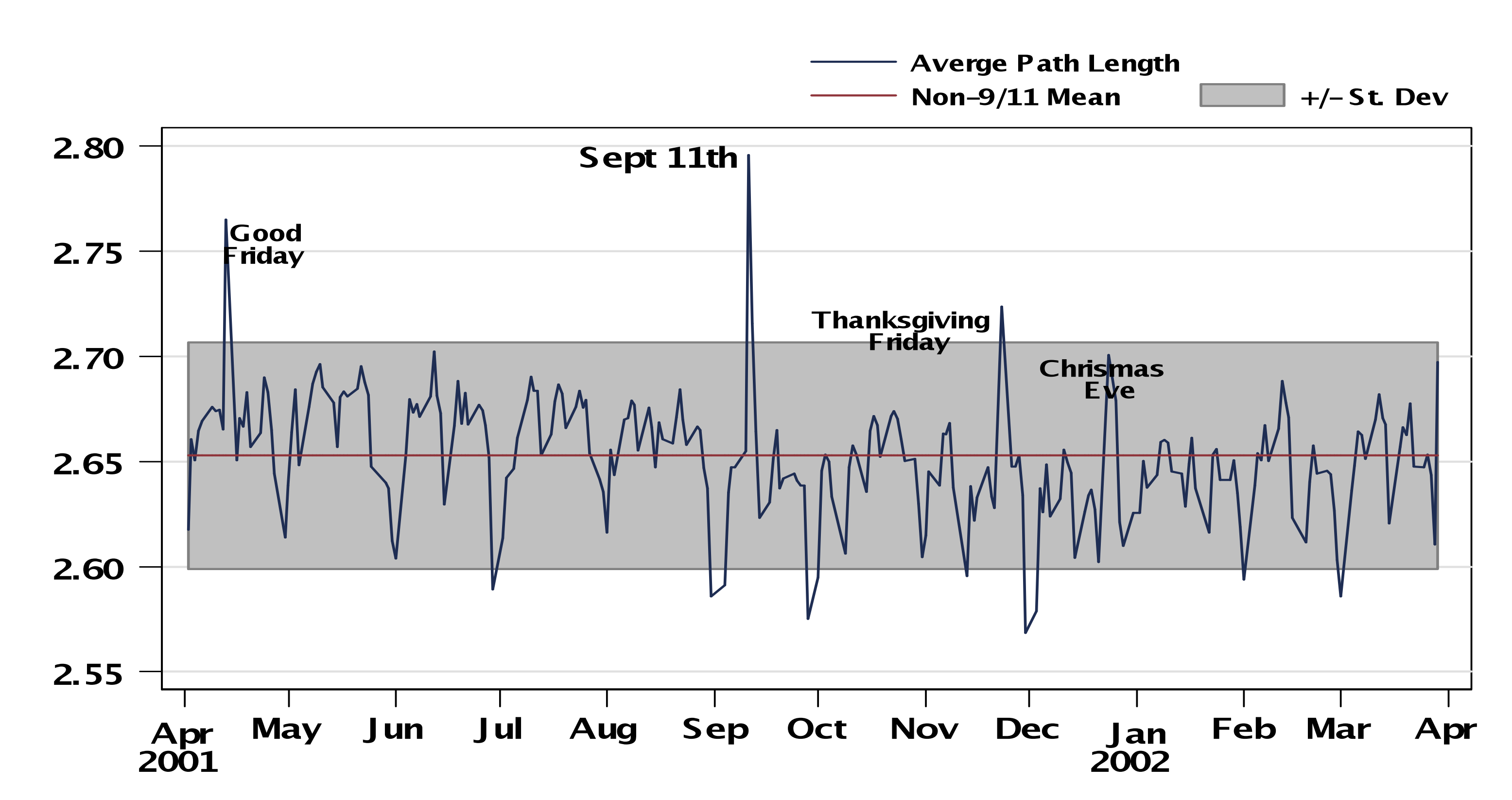
Number of Nodes in GSCC



Connectivity



Average Path Length on Fedwire



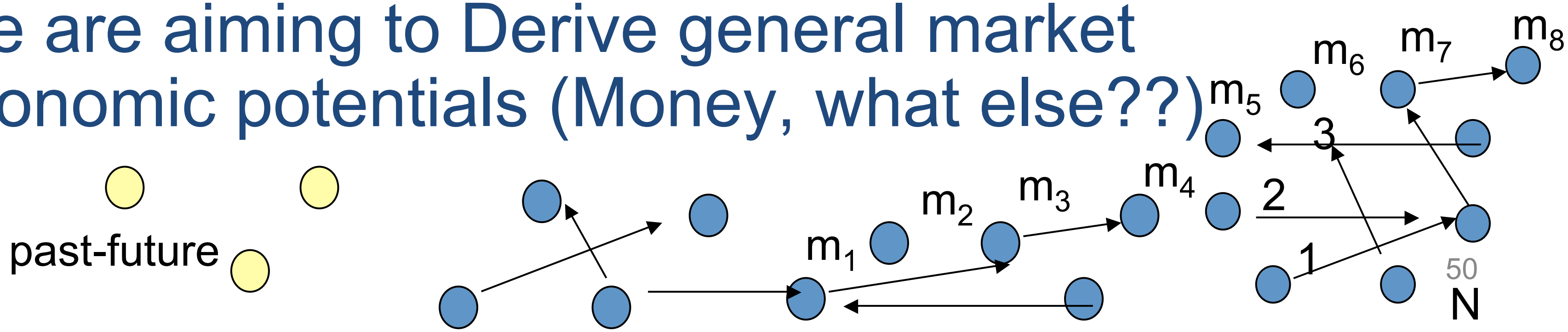
The average path length is ℓ=2.6±0.2 across our sample.

The mean eccentricity is ε=4.7±0.33,

The diameter ranges between D~ 6 and 7 across days

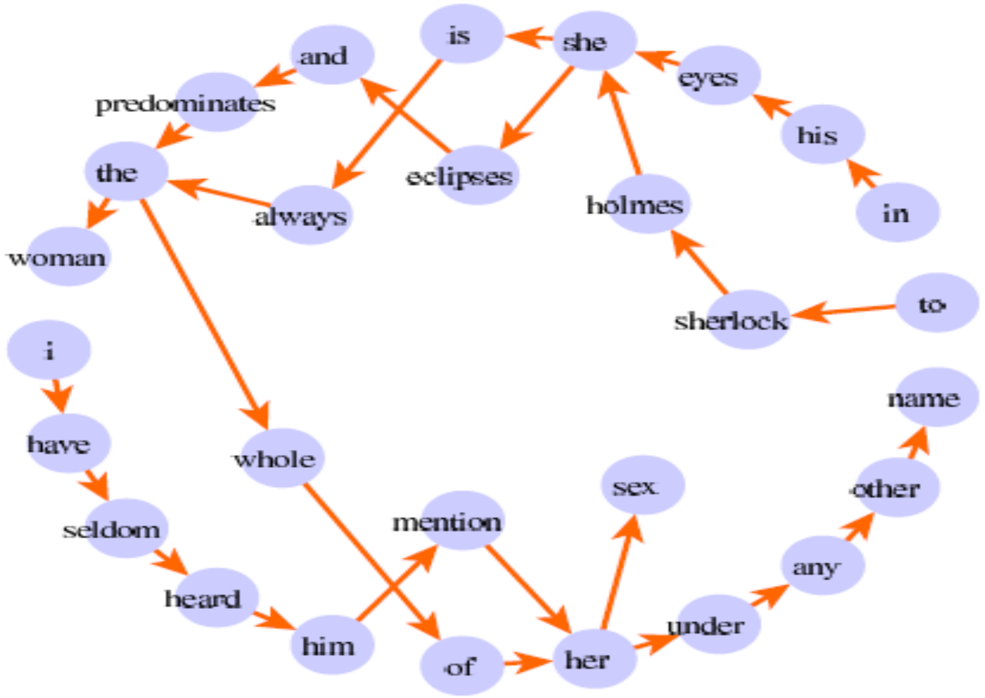
Our Aim: Using Statistical Mechanics to describe networks (economy)

- Generalization of Yakovenko et al approach:
- Introduction of general economic agents (may be a person, a bank or a company)
- Total number of agents N_i changes in time
- Trading of economic agents: in each moment of time (Yes- trading, No-Skipping)
- We are aiming to derive general network and market variables (Money, what else ??)
- We are aiming to Derive general market economic potentials (Money, what else??)

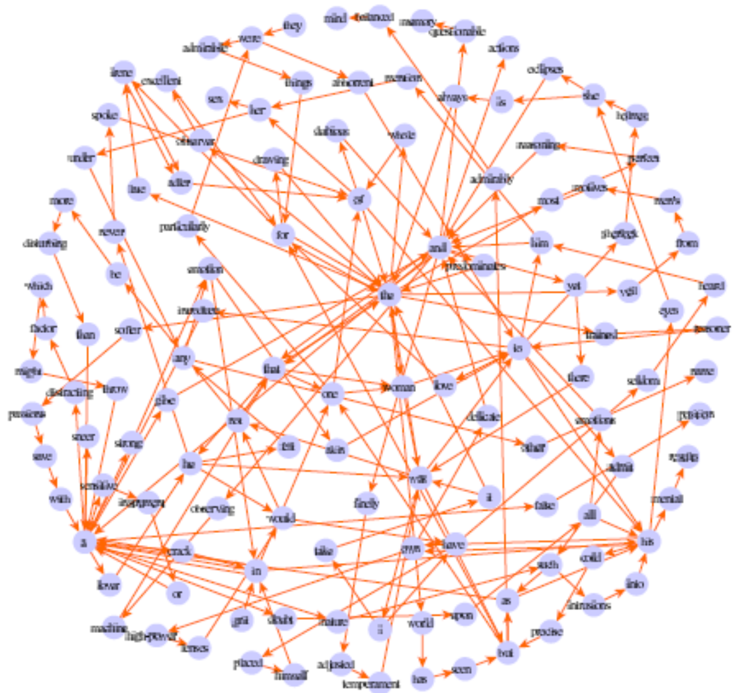


Market or society operation as dynamical network

Yes- trading, there is a link,



No-Skipping, no link



Many economic units (circles), which are interacting via trading, change the market state?

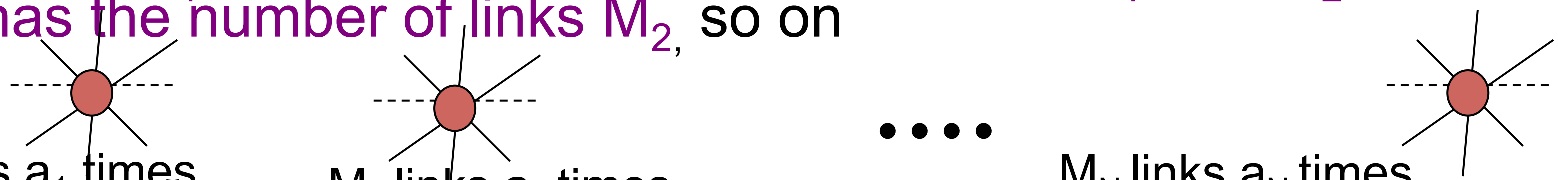
FVK 2010

Ensembles of networks

- Micro-Canonical: the number of nodes, N, and the number of links M are fixed, >the example is a random graph, its degree distribution is $P(M) = C_{N-1}^{M} p^{M} (1-p)^{N-1-M}$
- Canonical: the number of nodes, N,is fixed and the number of links M fluctuates, while its average is fixed, *P(M)?*
- Grand-Canonical: the number of nodes, N, and the number of links M fluctuate, while their average are fixed, *P(M)?*

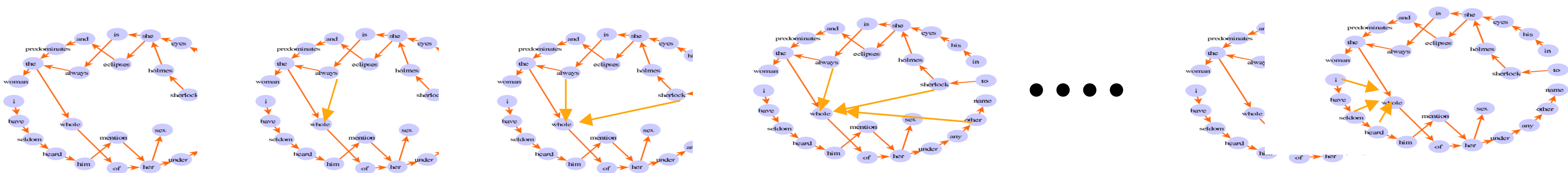
Snapshots of the market economy

- Assume that we made many (total number, A) snapshots during some long enough time interval, T
- During this time the money of workers changes
- Then among the total number of snapshots *each worker may have different amount of money and made a different number of trading (links)*
- Consider a single node, that is N=1, CANONICAL ENSEMBLE:
- Then a_1 times he has the number of links M_1 and a_2 times he has the number of links M_2, so on



M_1 links a_1 times M_2 links a_2 times …. M_N links a_N times

Find the most optimal configuration of the network or a probability of the node, P(m), to have m links:

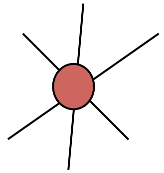


a_1 a_2 a_3 a_4 …. a_N

Market network snapshots

- A market mechanism mediates commodity exchange, chaotic,
- This means that during quite a long time interval t_0 any worker may get any amount of money but with different probability
- Total number of different configurations is $W = A!/(a_1!a_2!a_3!a_4!\ldots a_N!)$
- Then the most optimal configuration corresponds to the snapshot which is meeting the most often times .
- But we have to take into account the constraints:

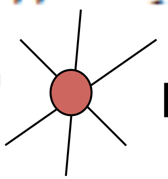
$$\sum_i a_i = A \qquad \text{and} \qquad \sum_i a_i M_i = AM.$$



M_i links

- A - total number of snapshots and M-average number of links a chosen node- degree of the graph(or money of the agent on the market)
- Problem: to find the maximum value or the most probable distribution from the total number of configurations *W (or log[W])*

$$\log W \sim A \log A - A - \sum_i a_i (\log a_i - 1) = A \log A - \sum_i a_i \log a_i.$$



M_i links

The most probable snapshots of the market: Boltzmann degree distribution

- The derivative gives that

$$0 = \frac{\partial}{\partial a_j}\left(\log W - \alpha \sum_i a_i - \beta \sum_i a_i M_i\right)$$

- After some calculations we obtain the probability of the node i to have the degree M_i :

$$\rho_i = \frac{a_i}{A} = \frac{1}{Z} e^{-\beta M_i}.$$

- The constant Z is equal to $$Z = \sum_i e^{-\beta M_i} \equiv \sum_{M_j} \Omega(M_j) e^{-\beta M_j},$$

- The degree of the network (degree of the graph) is

$$M = -\frac{\partial \log Z}{\partial \beta}.$$

Grand-Canonical

The number of nodes, M, and of links, N, fluctuate

Constraints: # of replicas; # of average links, # of average nodes
are equal to A, A M and A N, respectively

$$\sum_i a_i = A \qquad \sum_i a_i M_i = AM \qquad \sum_i a_i N_i = AN.$$

Average # of migrating agents does not depend on time

By optimisation or finding of the most probable snapshots via equation

$$0 = \frac{\partial}{\partial a_i}\left(\log W - \alpha \sum_i a_i - \beta \sum_i a_i M_i - \gamma \sum_i a_i N_i\right).$$

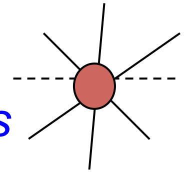
We find the network degree distribution or
a probability of the network to have M_i links and N_i nodes in the form:

$$\rho_i = \frac{a_i}{A} = \frac{e^{-\beta(M_i - \mu N_i)}}{Z}.$$

Where the partition function is

$$Z = \sum_i e^{-\beta(M_i - \mu N_i)}.$$

Individual or degree distribution



m_r links

N_i- total number of nodes in the network

$$N_i = \sum_r n_r \quad \text{and} \quad M_i = \sum_r m_r n_r.$$

M_i -total number of links in the network

$$Z = \sum_i e^{-\beta(M_i - \mu N_i)}$$

Let n_r=0,1,2,…, ∞

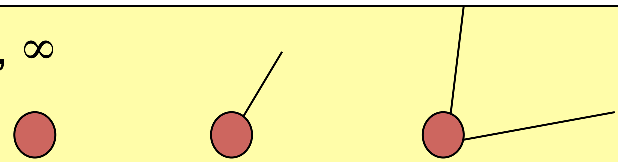
$$= \sum_{n_1, n_2, \ldots} e^{-\beta(n_1 m_1 + n_2 m_2 + \cdots - \mu n_1 - \mu n_2 - \ldots)}$$

$$= \prod_r \sum_{n_r} e^{-\beta n_r(m_r - \mu)}$$

- Estimate the partition function *Z*
- Nodes in a graph are indistinguishible
- Making a summation for each node, which may have any # of links

Let n_r = 0, 1, 2, …, ∞

m_r =1, 2, 3, …, …, ∞



$$Z = e^{-\beta 0(m_r - \mu)} + e^{-\beta 1(m_r - \mu)} + e^{-\beta 2(m_r - \mu)} + e^{-\beta 3(m_r - \mu)} + \cdots$$

Using the Partition function *Z* - find the degree distribution

- Taking into account that each node may have any number of links we have *Z*

$$Z = \prod_r \frac{1}{1 - e^{-\beta(m_r - \mu)}}.$$

- Then we find the total average number of the links

$$N = \frac{1}{\beta}\left(\frac{\partial \log Z}{\partial \mu}\right)_\beta = \sum_r \frac{1}{e^{\beta(m_r - \mu)} - 1}.$$

The degree distribution of network with fluctuation in N and M

- Average number of nodes having m_r links
- Or degree distribution

$$\bar{n}(m_r) = \frac{g_r}{e^{\beta(m_r - \mu)} - 1}.$$

- This is Bose-Einstein distribution !!!, used in physics and economics

- The degree of the graph is

$$M = \sum_r \frac{g_r m_r}{e^{\beta(m_r - \mu)} - 1}.$$

Analogy between 3 systems

1. Networks: number of links in a node, k_i
2. Gas of Particle: energy of particles, E_i
3. Economics: money of agents in financial network, m_i

These many-body systems may be described by either

by Boltzmann distribution or

$$\rho_i = \frac{a_i}{A} = \frac{1}{Z} e^{-\beta F_i}$$

by Bose-Einstein distribution

$$n(m) = \frac{1}{\exp\left(\frac{m - \mu}{T}\right) - 1}$$

Total average money

- the salary and debt distribution:

$$\bar{n}(m_r) = \frac{g_r}{e^{\beta(m_r-\mu)}-1}.$$

$$n(d_r) = \frac{g_r}{e^{\beta(d_r+\mu)}-1}$$

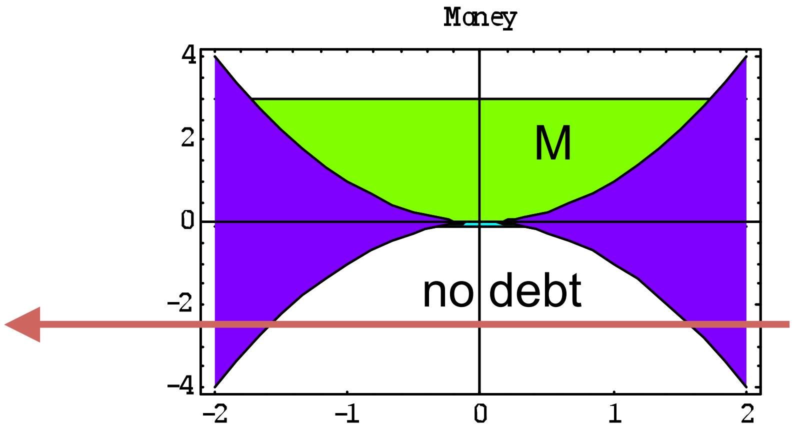
- The same “chemical” potential μ in both eqs!
- Total average debt D and money M are connected by μ and inter dependent !!!

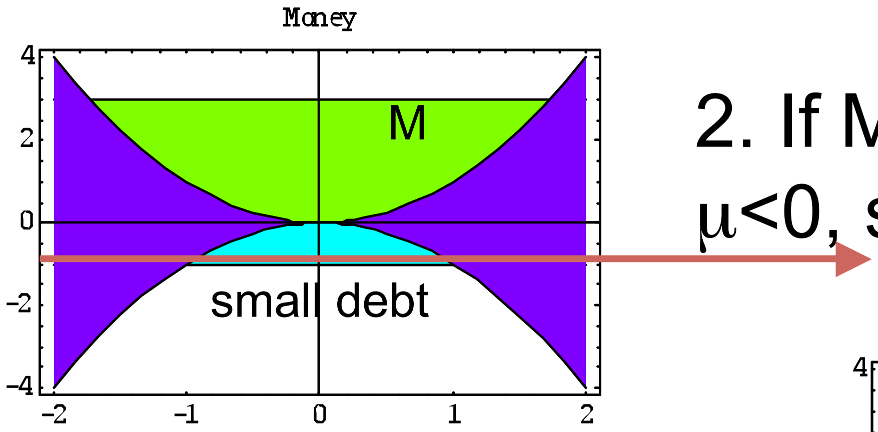
$$D = \sum_r \frac{d_r g_r}{e^{\beta(d_r+\mu)}-1}$$

$$M = \sum_r \frac{g_r m_r}{e^{\beta(m_r-\mu)}-1}.$$

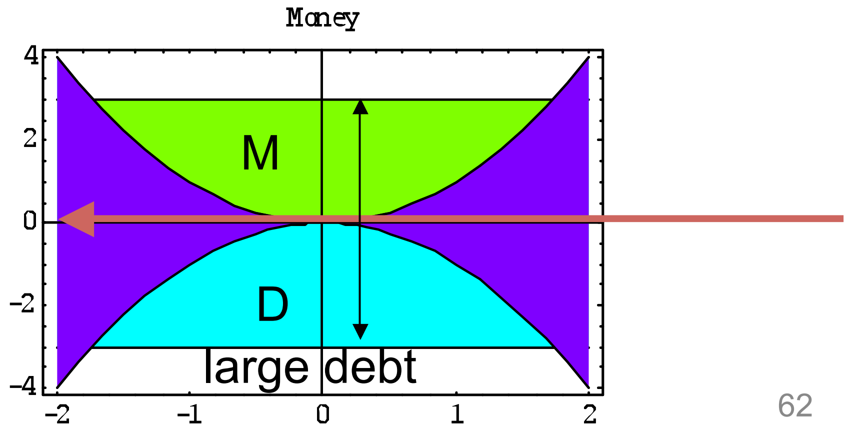
Economic Potential μ

1. If M>0, D=0, μ<0,
Large negative value





2. If M>0, D>0, but M>>D
μ<0, small negative value



3. If M=D, μ=0 !!!!

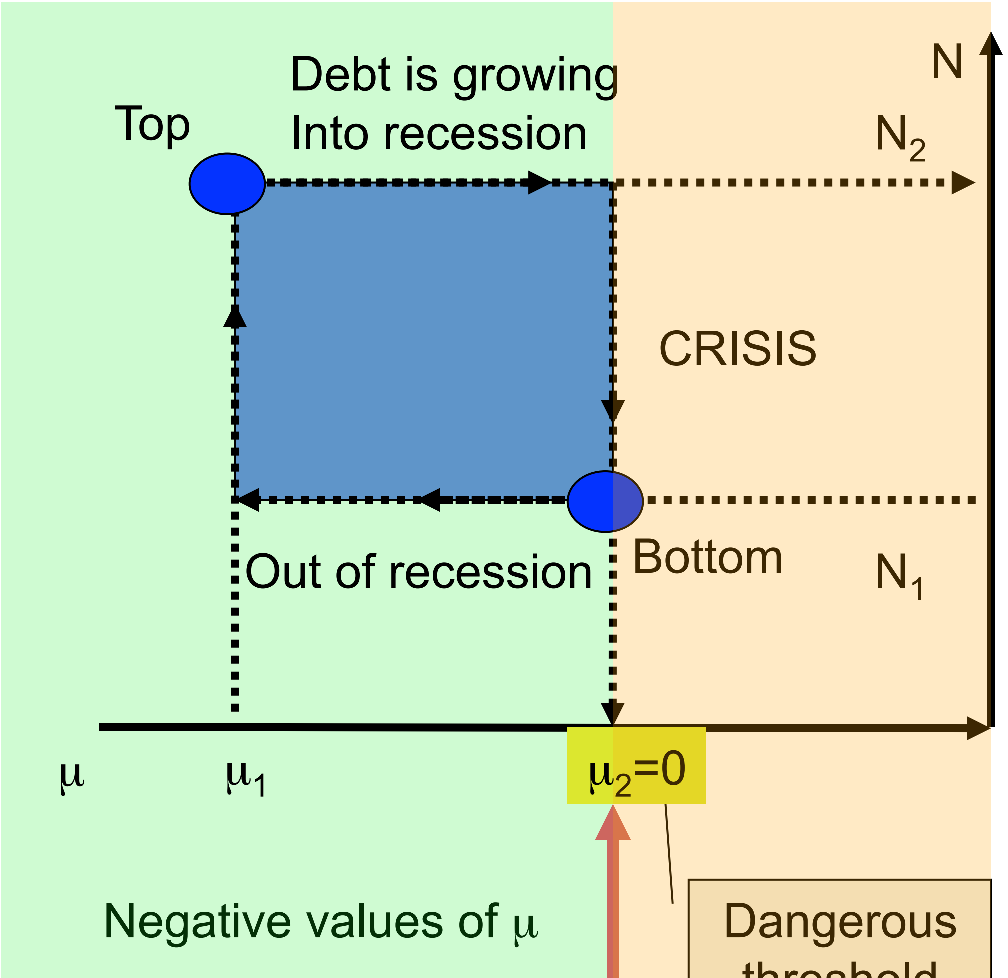
Economic Potential μ =0 Bose-Einstein condensation

- This means that majority of agents have zero salary, ie m=0. As no job agents
- No salary = salary with zero income
- Unemployment is Bose-Einstein condensation
- May be very large number of people with m=0
- Economically they are all indistinguishible

Summary: This is situation of financial crisis!

Question: How it is happen?, can we predict this?

Financial Crisis arises in a la' 'Carnot' circle

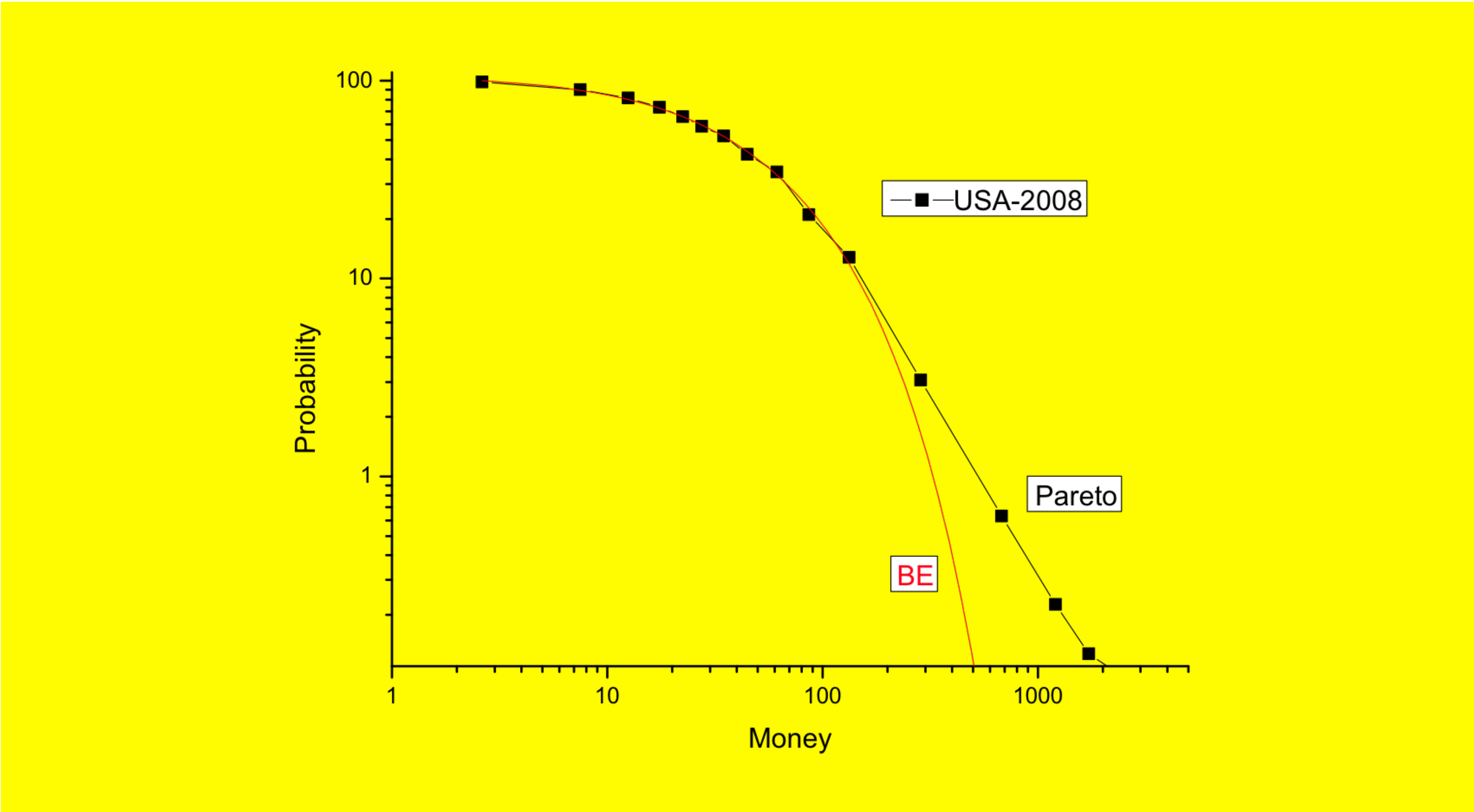


4 states of market economy:

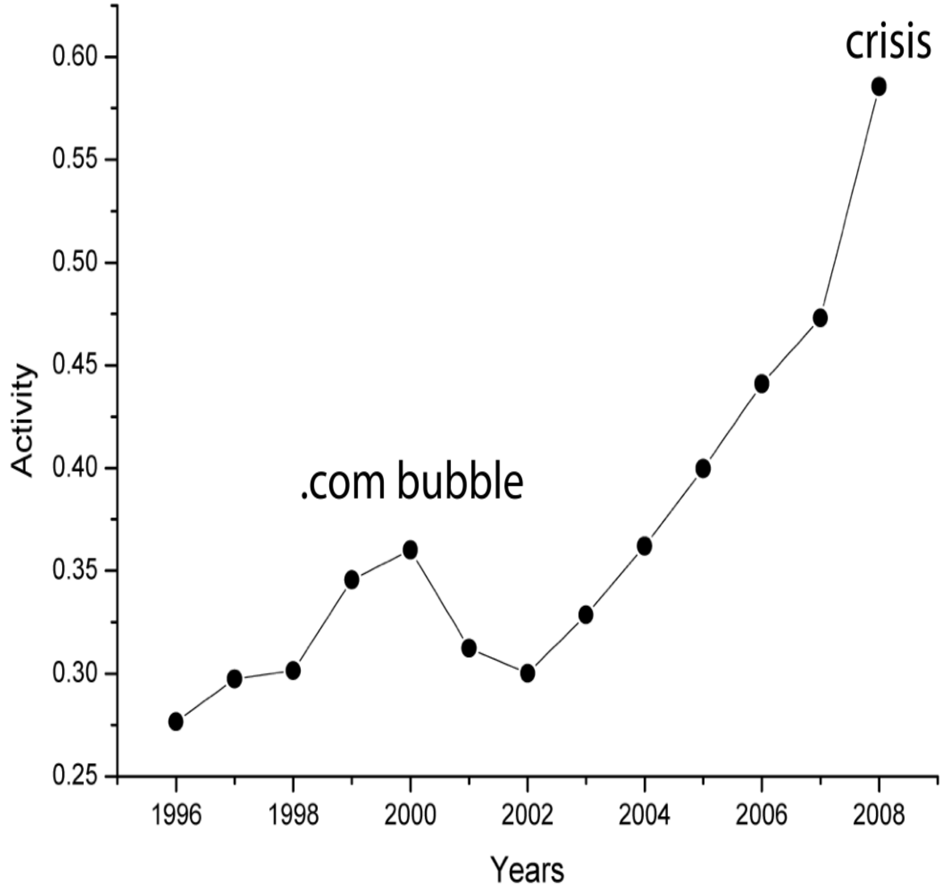
- 1.Growing Debt leads into recession
- 2.Crisis
- 3.Out of crisis
- 4.Up-turn

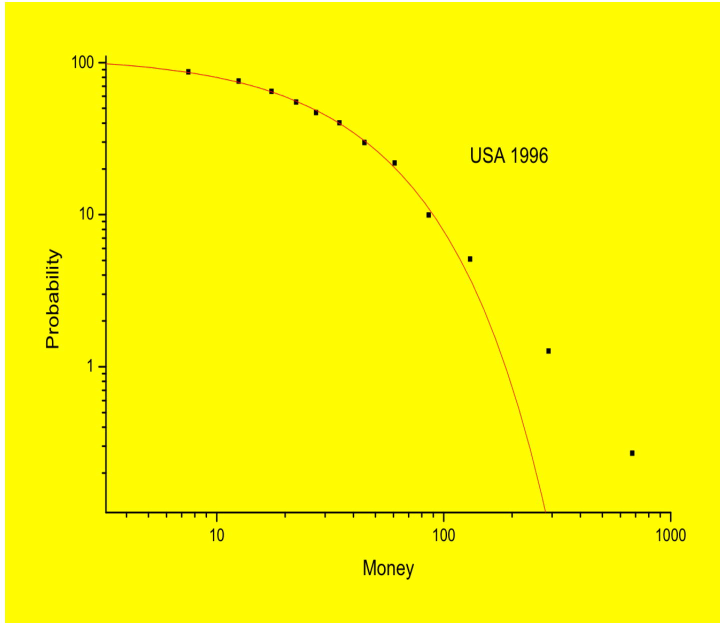
- Crisis corresponds to $\mu_2=0$, that is, Bose-condensation
- This is massive company closures, unemployment

USA Income distribution



Economics of USA



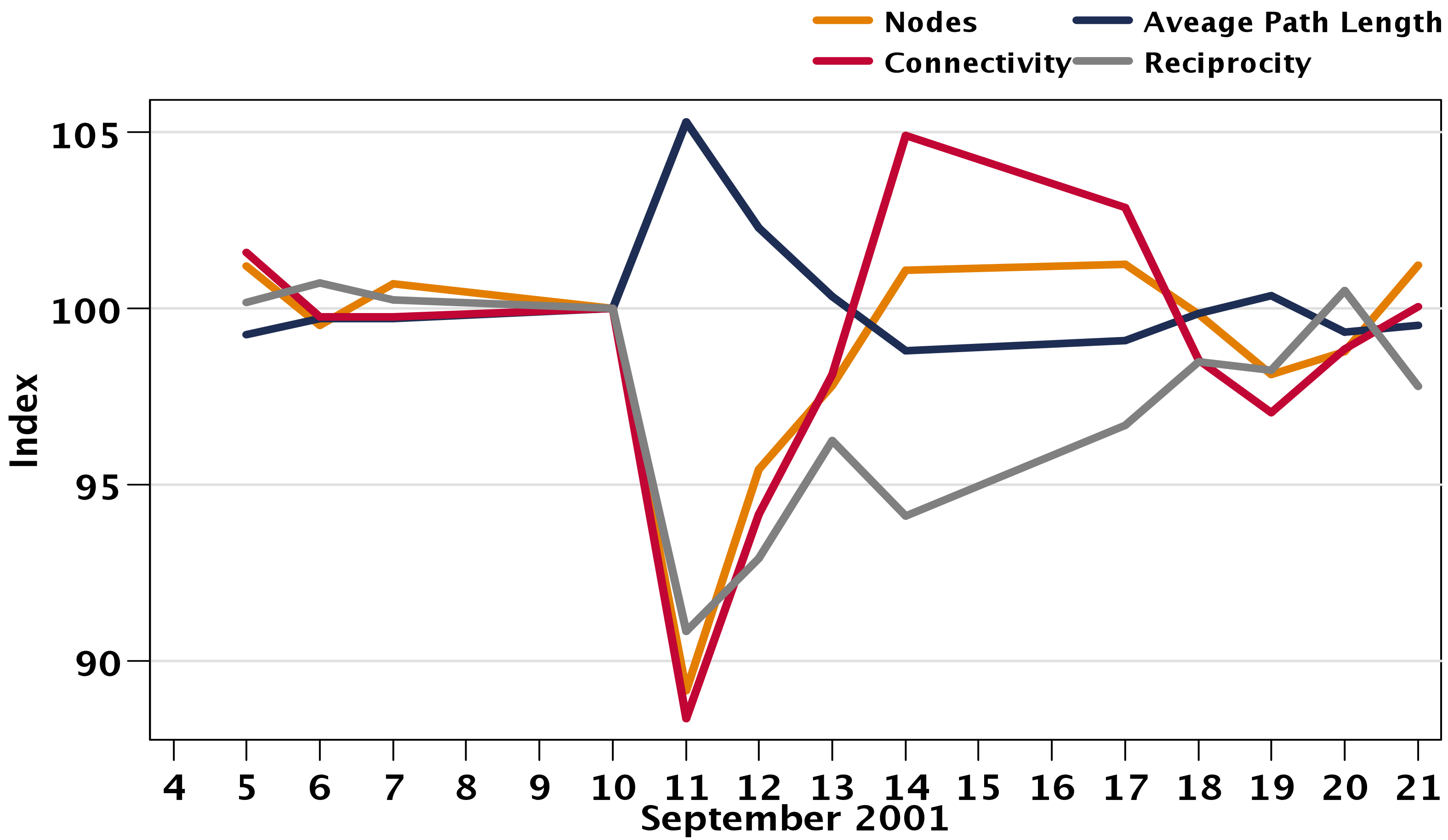


Summary

- Applied Statistical Mechanics to Networks and Market Economy
- Derived Exponential (Boltzman) distribution of money and income (confirm Yakovenko et al)
- Derived Bose-Einstein distribution of links in financial networks, money, income and wealth
- Derived potentials and variables more market economy (include a description of money, income, debt and wealth)
- Describe formation of financial crisis quantitatively as BEC transition

Conclusion: The length of the global finance crises depends on the value of global debt

9/11 Network changes



Note: 100 = September 10th, 2001.

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