A hálózatok világában

Barabási Albert-László

CENTER FOR COMPLEX NETWORKS RESEARCH

NORTHEASTERN UNIVERSITY

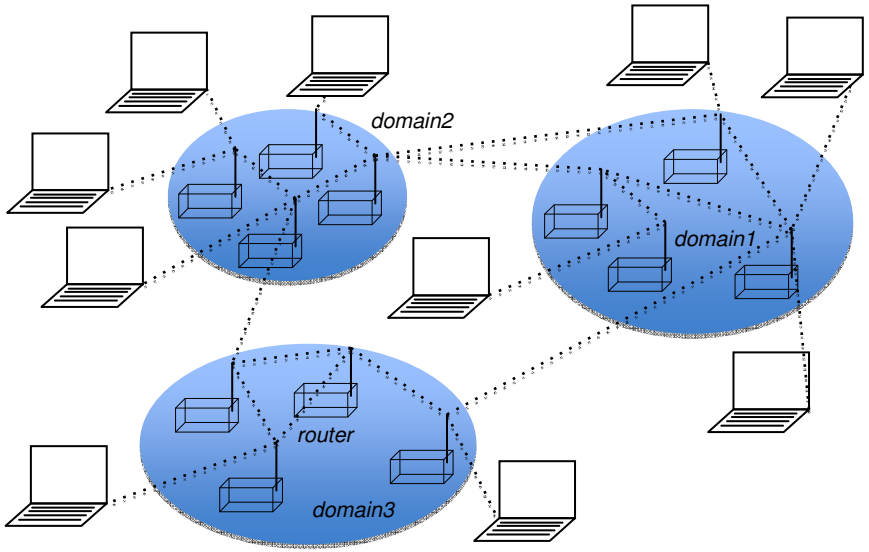
DEPARTMENT OF MEDICINE AND CCSB

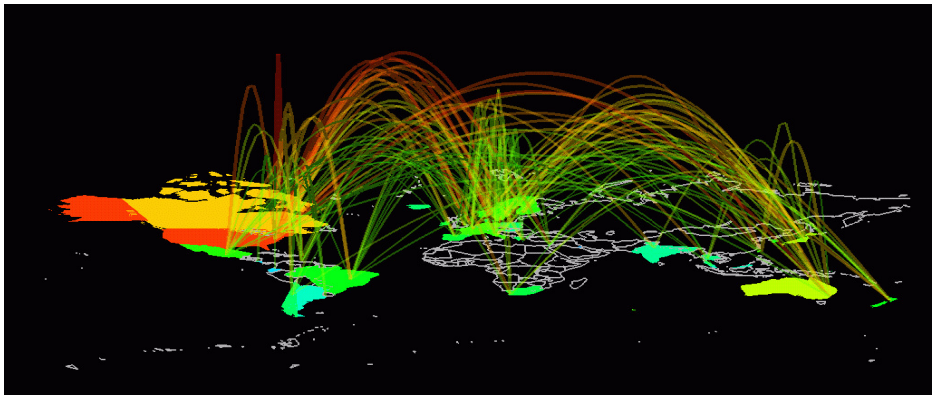
HARVARD MEDICAL SCHOOL

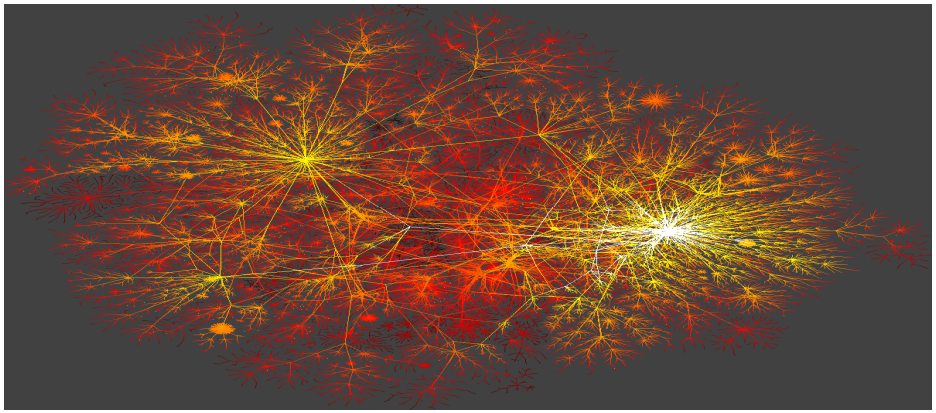
CENTRAL EUROPEAN UNIVERSITY, BUDAPEST

www.BarabasiLab.com

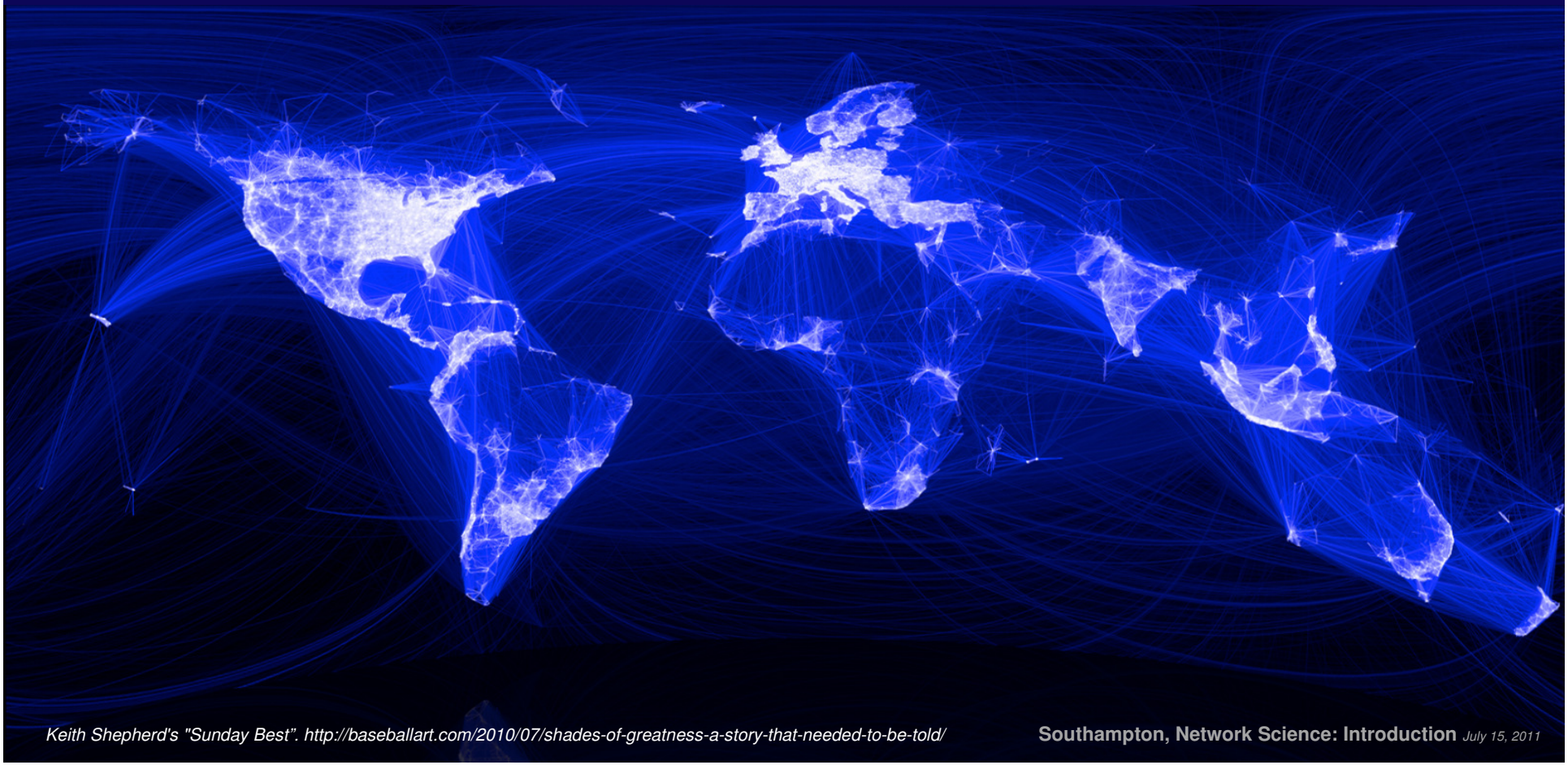
INTERNET





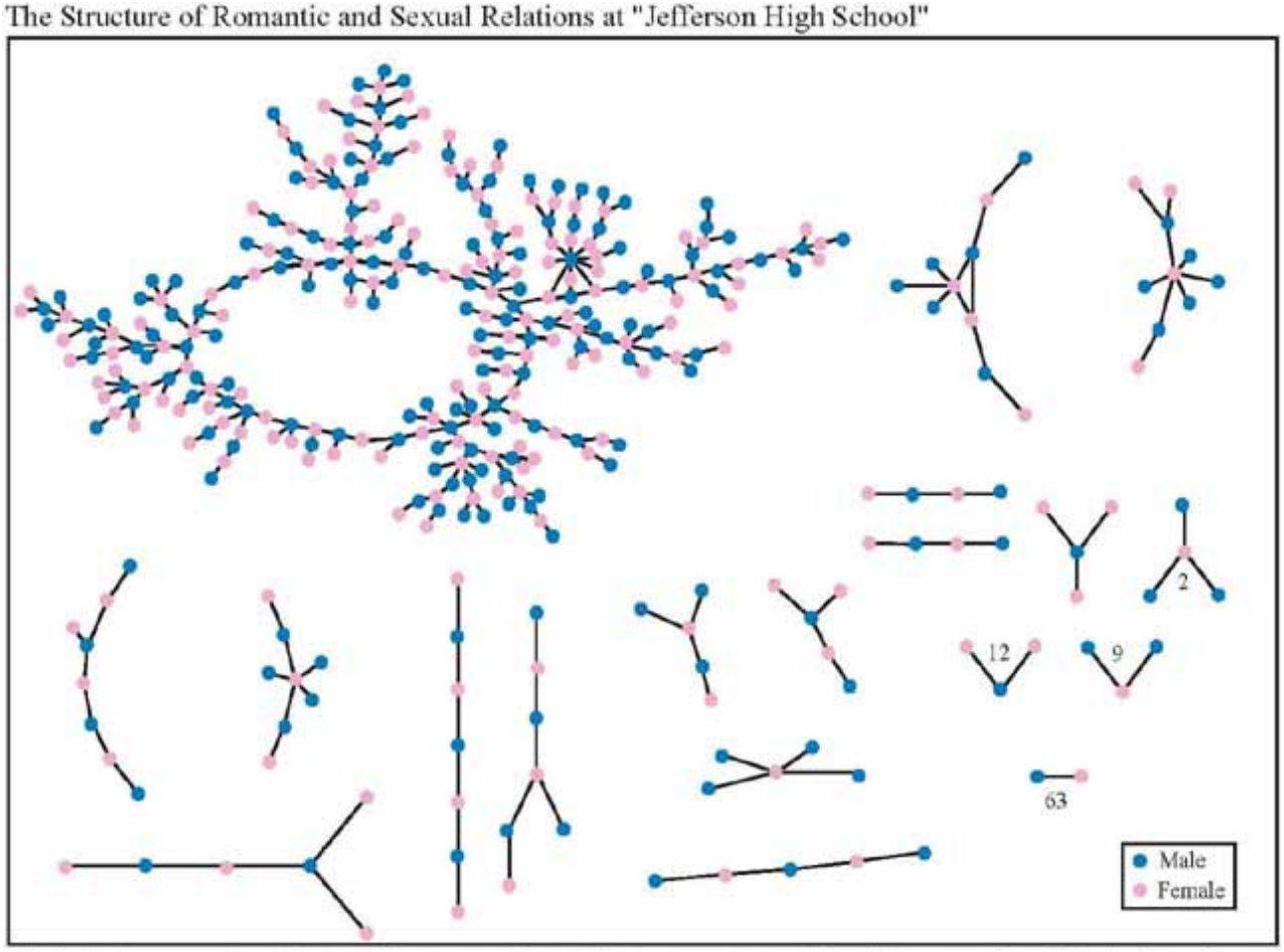


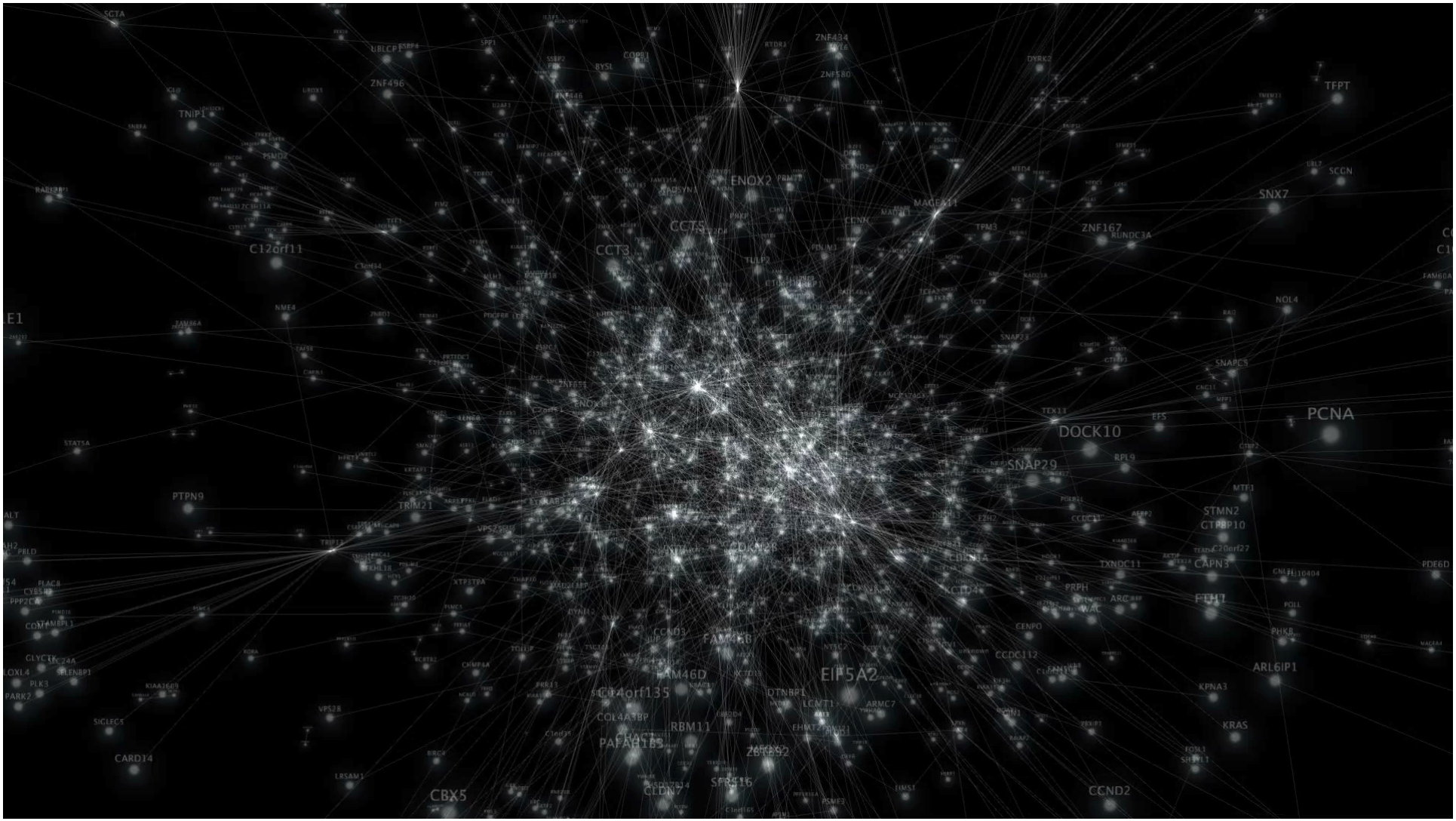
SOCIETY Facebook: The Social Graph



Keith Shepherd's "Sunday Best". http://baseballart.com/2010/07/shades-of-greatness-a-story-that-needed-to-be-told/

HIGH SCHOOL ROMANTIC NETWORKS




SCTA
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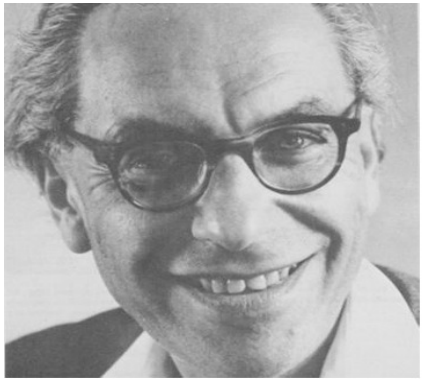
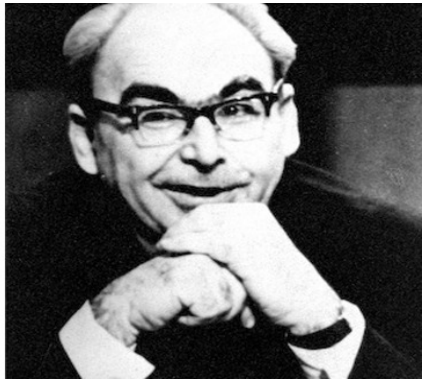
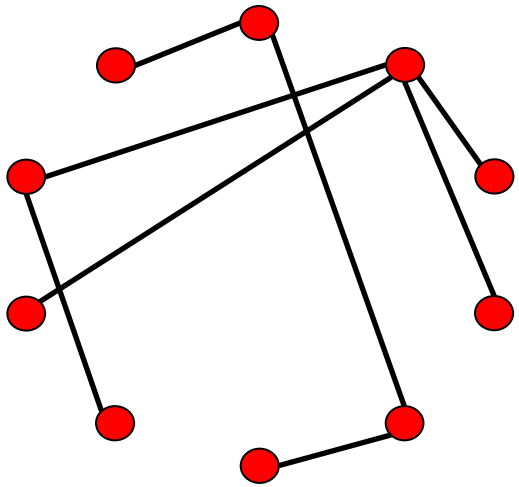
ENOX2
MAGEA11
SNX7
TFPT
ZNF167
C12orf11
CCT5
CCT3
NOL4
PCNA
DOCK10
SNAP29
SNAPC5
PTPN9
TRIM21
STMN2
GTPBP10
CAPN3
EIF5A2
ARL6IP1
KRAS
CARD14
CBX5
CCND2
RBM11
DTNBP1
KPNA3

RANDOM NETWORK MODEL

Pál Erdös
(1913-1996)





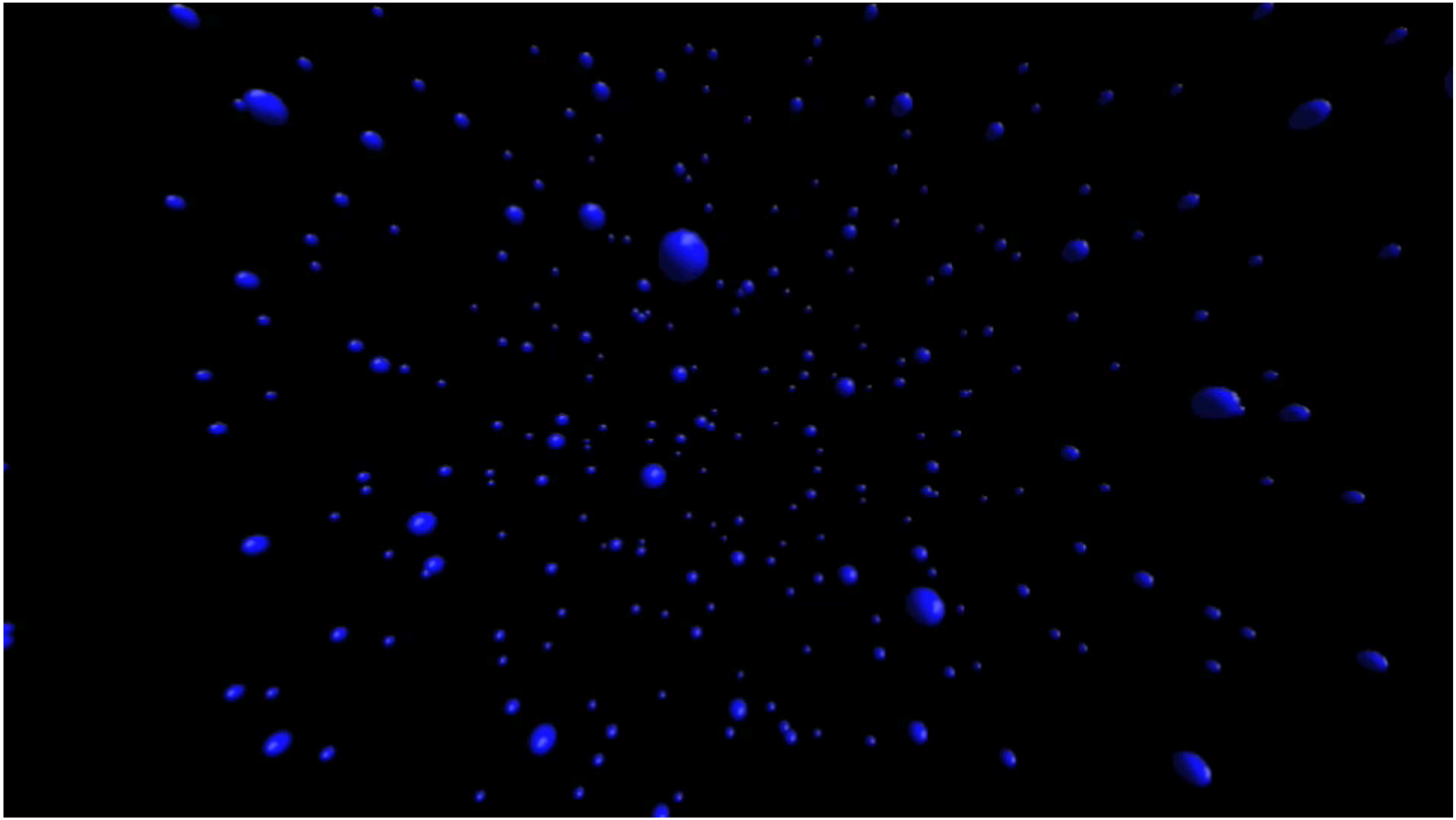


Erdös-Rényi model (1960)

Connect with probability p

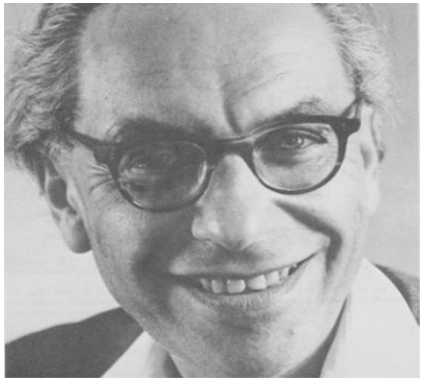
p=1/6 N=10

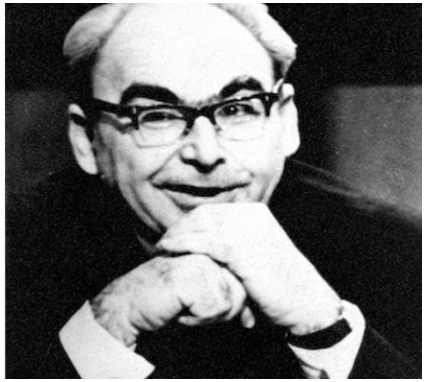
⟨k⟩ ~ 1.5

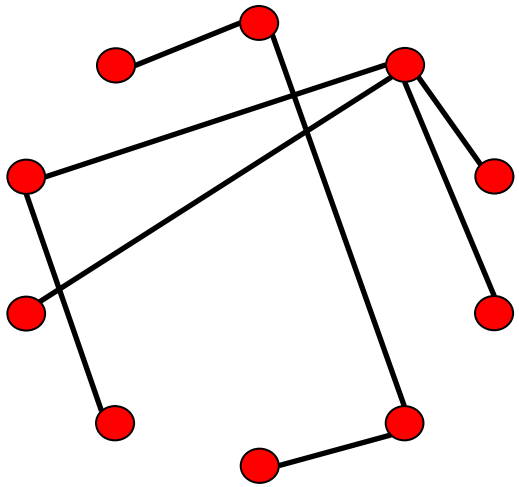


RANDOM NETWORK MODEL

Pál Erdös
(1913-1996)







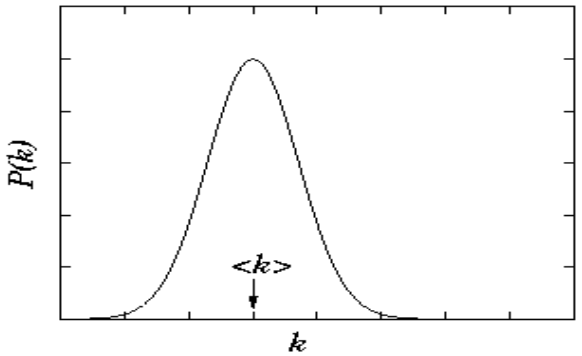
Erdös-Rényi model (1960)

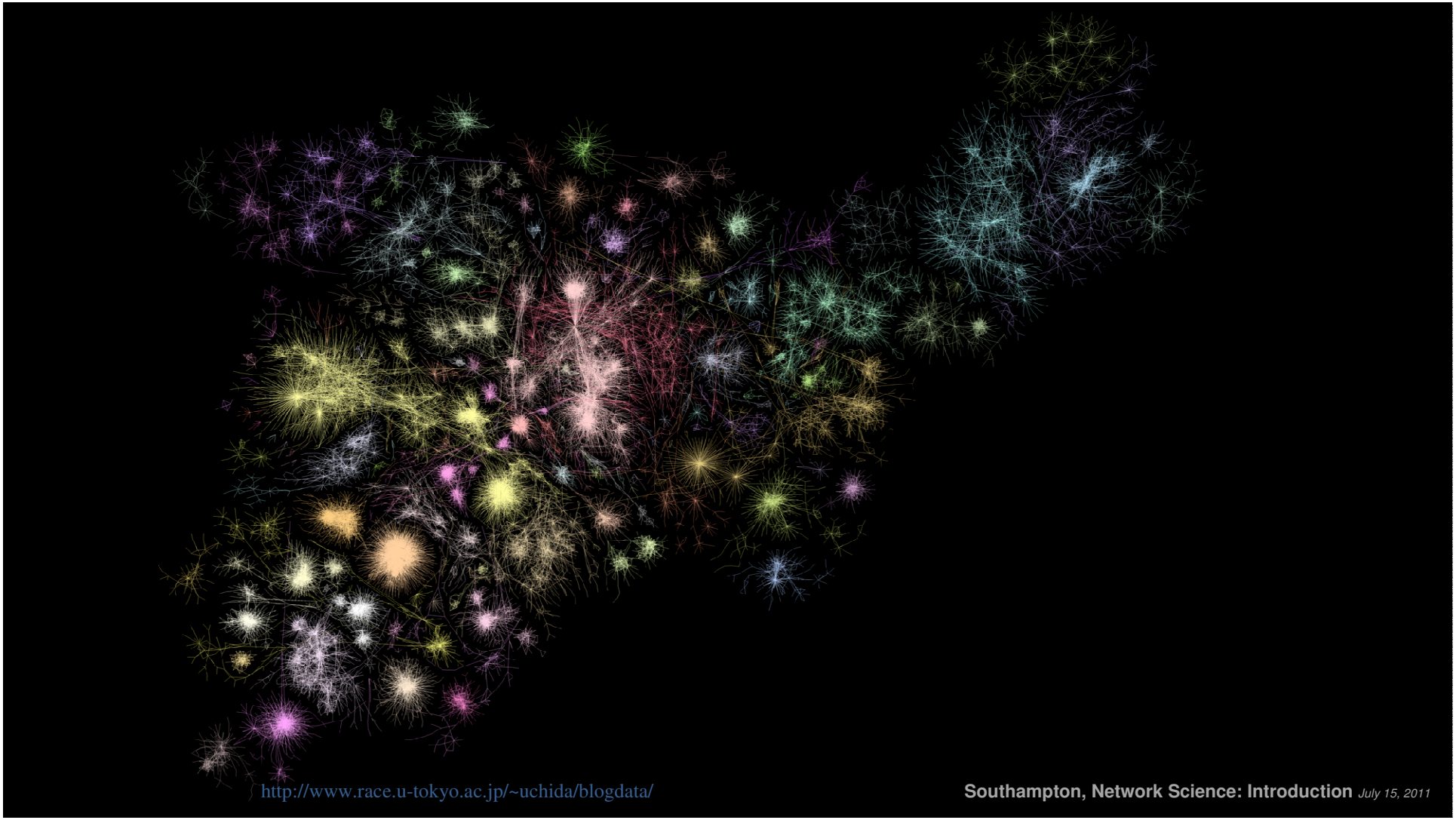
Connect with probability p

p=1/6 N=10

⟨k⟩ ~ 1.5

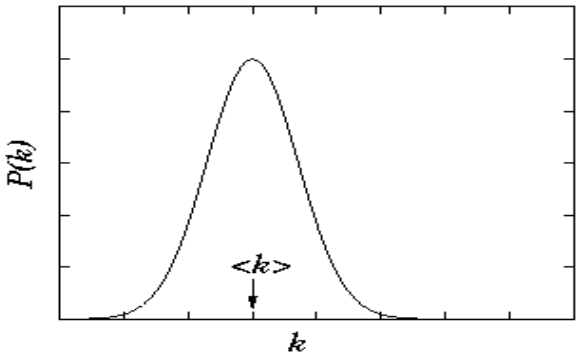
Degree distribution




http://www.race.u-tokyo.ac.jp/~uchida/blogdata/

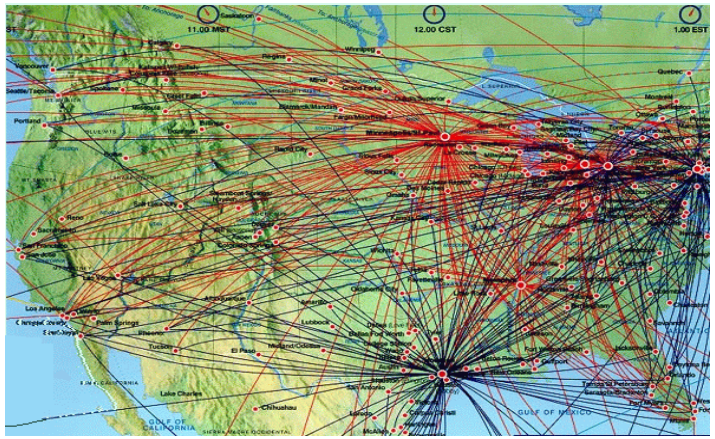
WORLD WIDE WEB

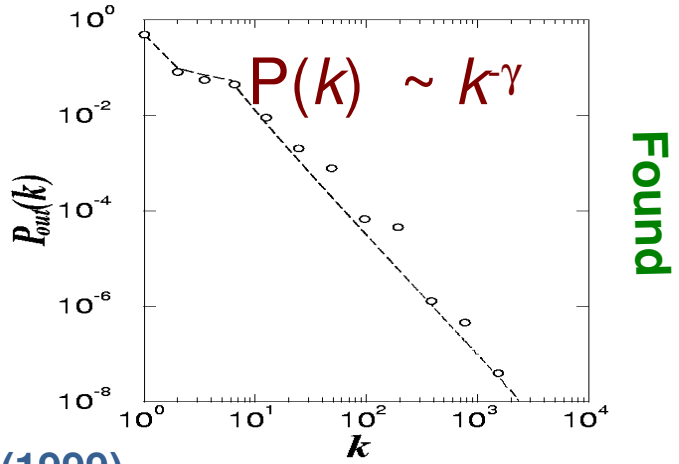
Random Network



Expected

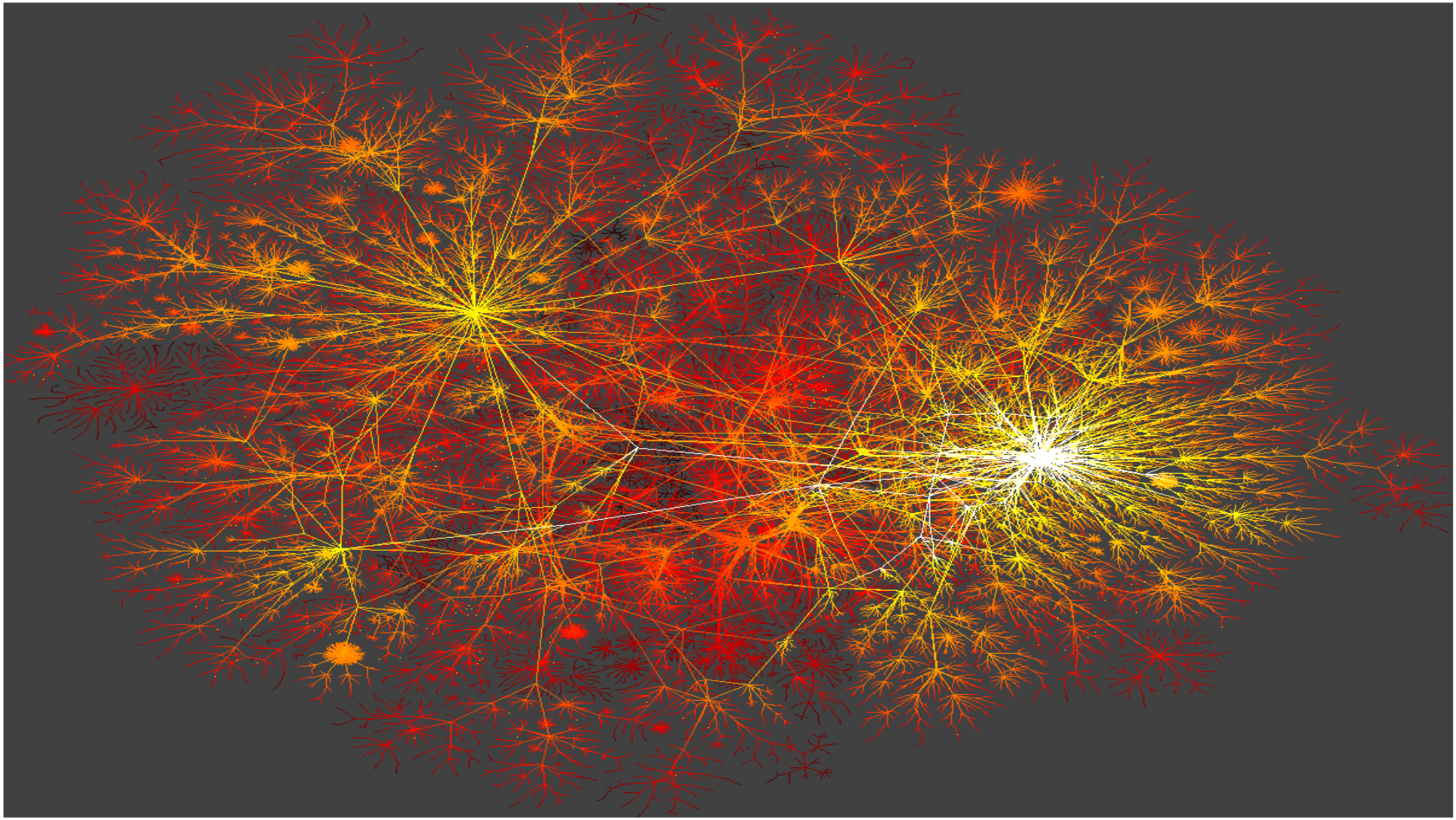
Scale-free Network





Found

R. Albert, H. Jeong, A-L Barabasi, *Nature*, 401 130 (1999).



ACTOR NETWORK

Austin Powers:
The spy who
shagged me

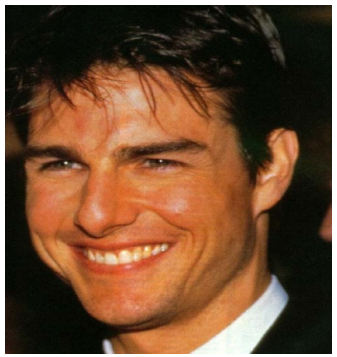
Robert Wagner

Let's make
it legal

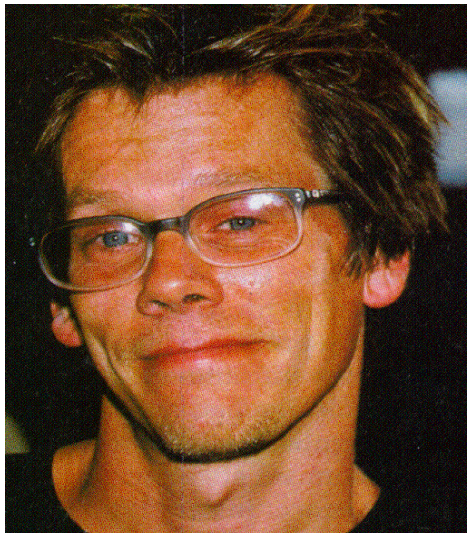
Wild Things

What Price Glory

Barry Norton



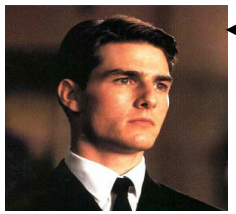
**A Few
Good Men**



**Monsieur
Verdoux**

ACTOR NETWORK

Nodes: actors
Links: cast jointly

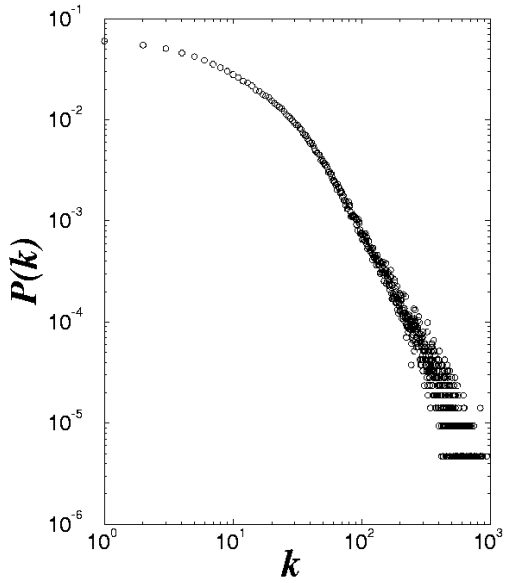


Days of Thunder (1990)
Far and Away (1992)
Eyes Wide Shut (1999)

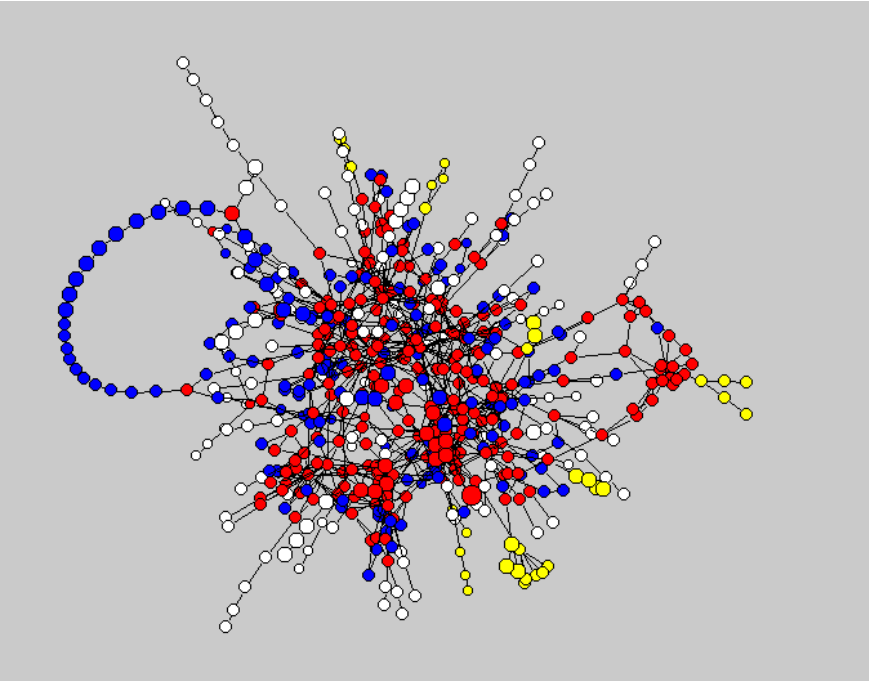
N = 212,250 actors $\langle k \rangle = 28.78$

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

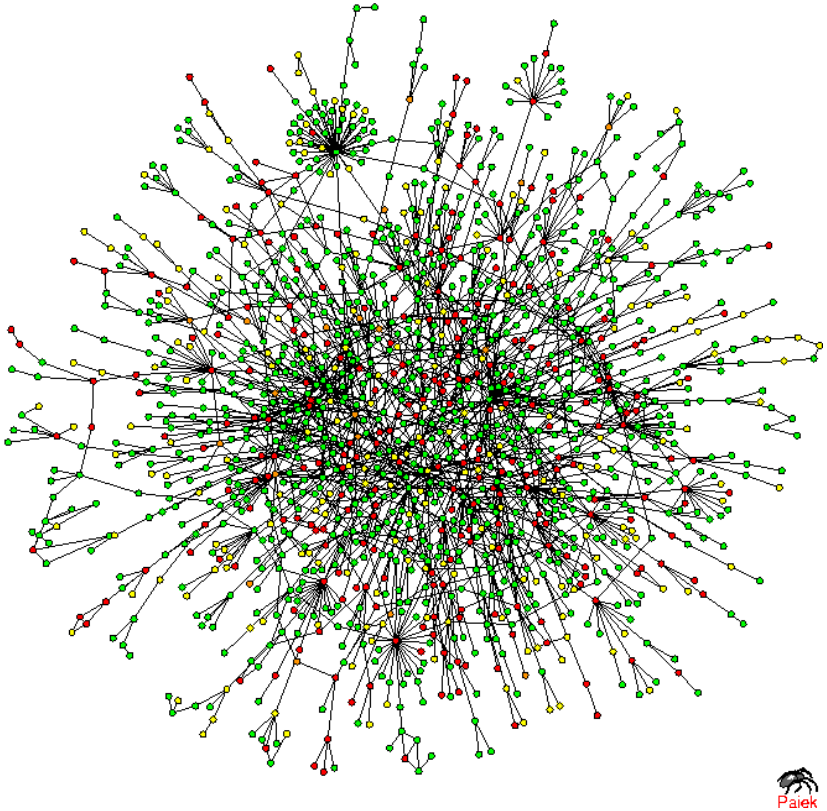
$\gamma = 2.3$



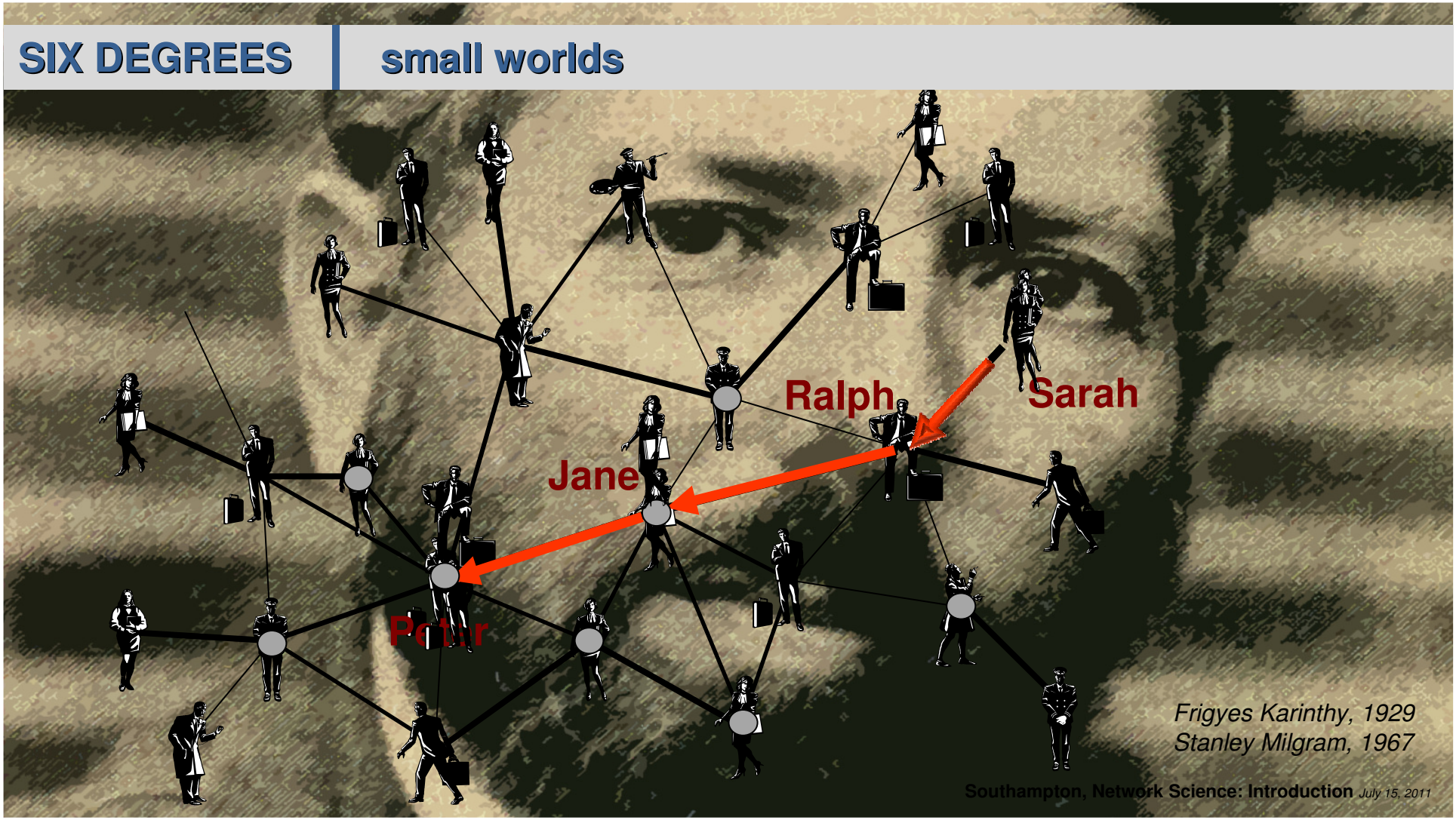
METABOLIC NETWORK



PROTEIN INTERACTIONS



SIX DEGREES | small worlds



Frigyes Karinthy, 1929
Stanley Milgram, 1967

Frigyes Karinthy (1887-1938)

1929, Karinthy Frigyes

“Tessék egy akármilyen maghatározható egyént kijelölni a Föld másfél milliárd lakója közül, bármelyik pontján a Földnek– ő fogadást ajánl, hogy legföljebb öt, más egyénen keresztül, kik közül az egyik neki személyes ismerőse, kapcsolatot tud létesiteni az illetővel, csupa közvetlen ismeretség alapon”

MANY REAL WORLD NETWORKS HAVE A SIMILAR ARCHITECTURE:

Scale-free networks

WWW, Internet (routers and domains), electronic circuits, computer software, movie actors, coauthorship networks, sexual web, instant messaging, email web, citations, phone calls, metabolic, protein interaction, protein domains, brain function web, linguistic networks, comic book characters, international trade, bank system, encryption trust net, energy landscapes, earthquakes, astrophysical network…

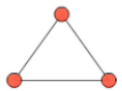
ORIGIN OF SF NETWORKS: Growth and preferential attachment

(1) Networks continuously expand by the addition of new nodes

WWW : **addition of new documents**

(2) New nodes prefer to link to highly connected nodes.

WWW : **linking to well known sites**



Barabási & Albert, *Science* **286,** 509 (1999)

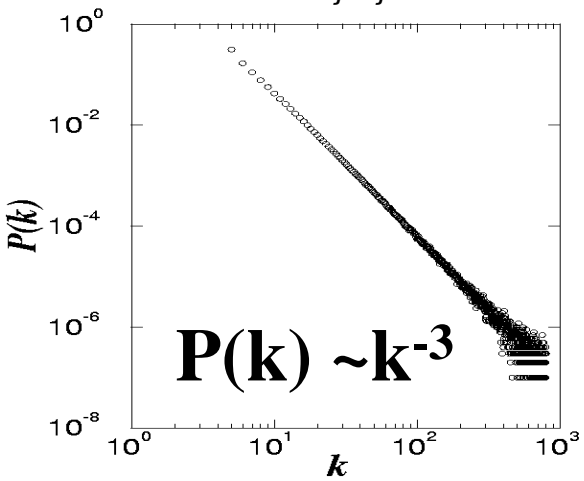
GROWTH:

add a new node with m links

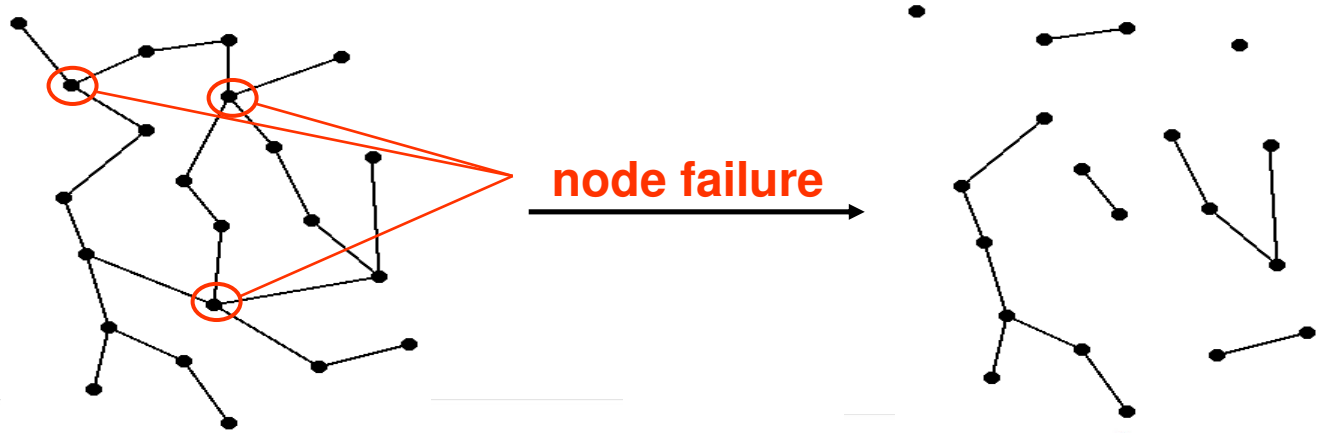
PREFERENTIAL ATTACHMENT:

the probability that a node connects to a node with *k* links is proportional to *k*.

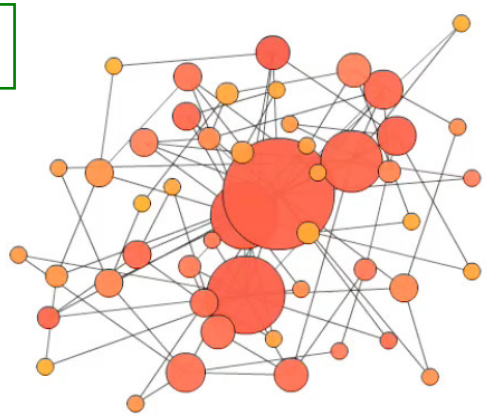
$$\Pi(k_i) = \frac{k_i}{\sum_j k_j}$$



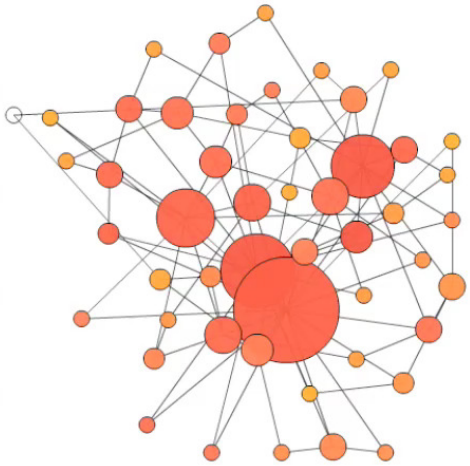
ROBUSTNESS OF SCALE-FREE NETWORKS



Failures



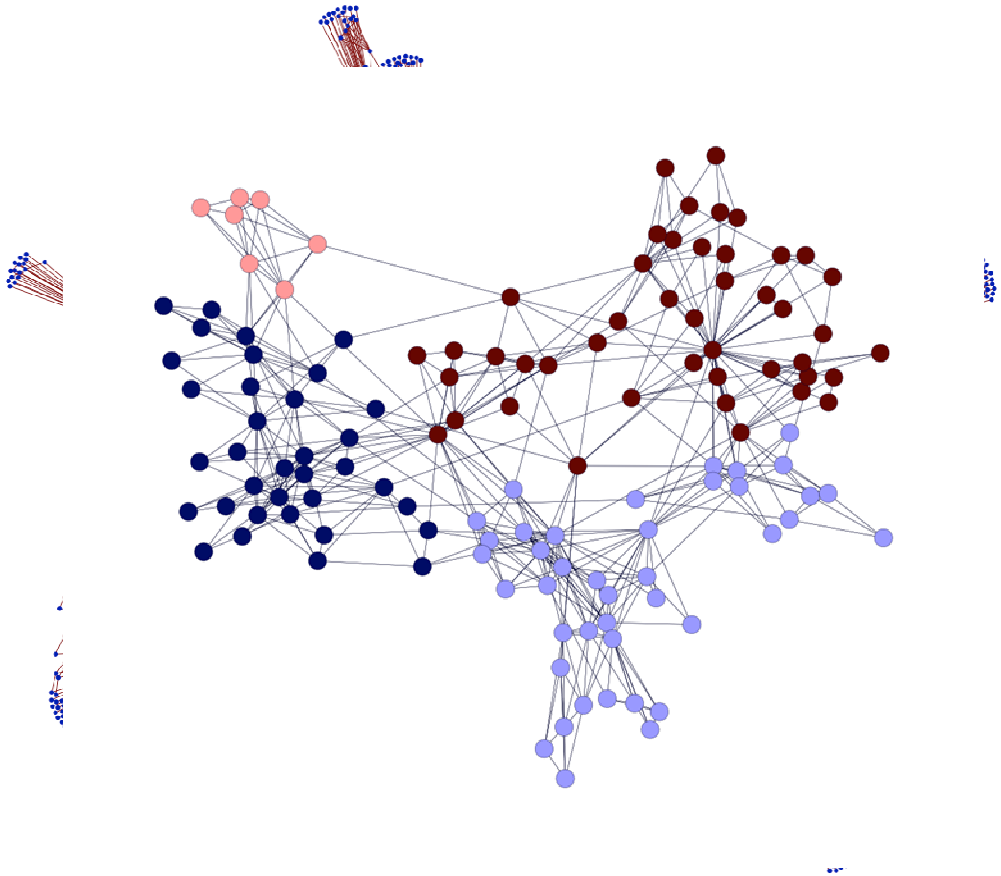
Attacks



Albert, Jeong, Barabási, *Nature* **406** 378 (2000)

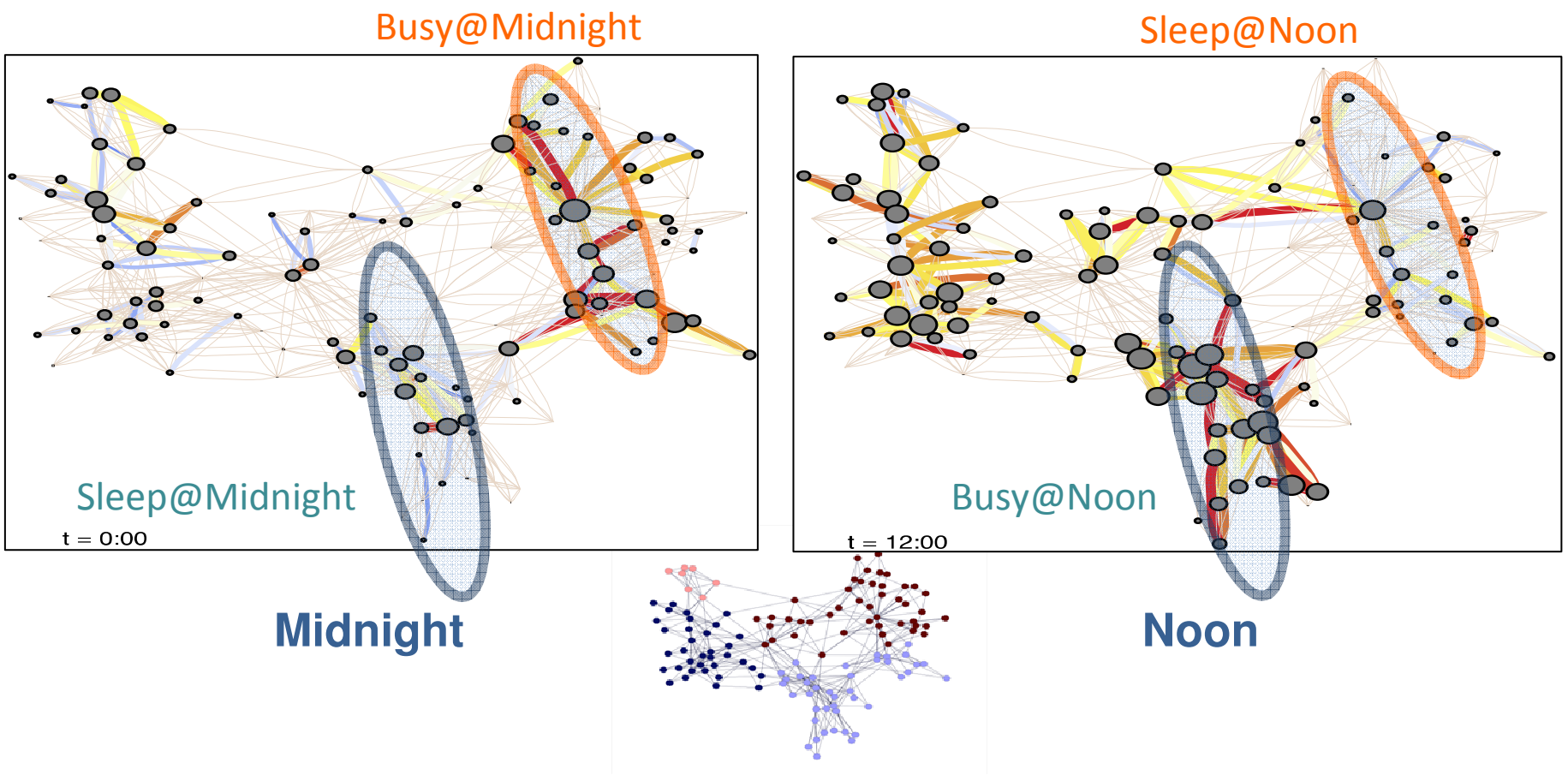
The X's Law

Nodes form communities



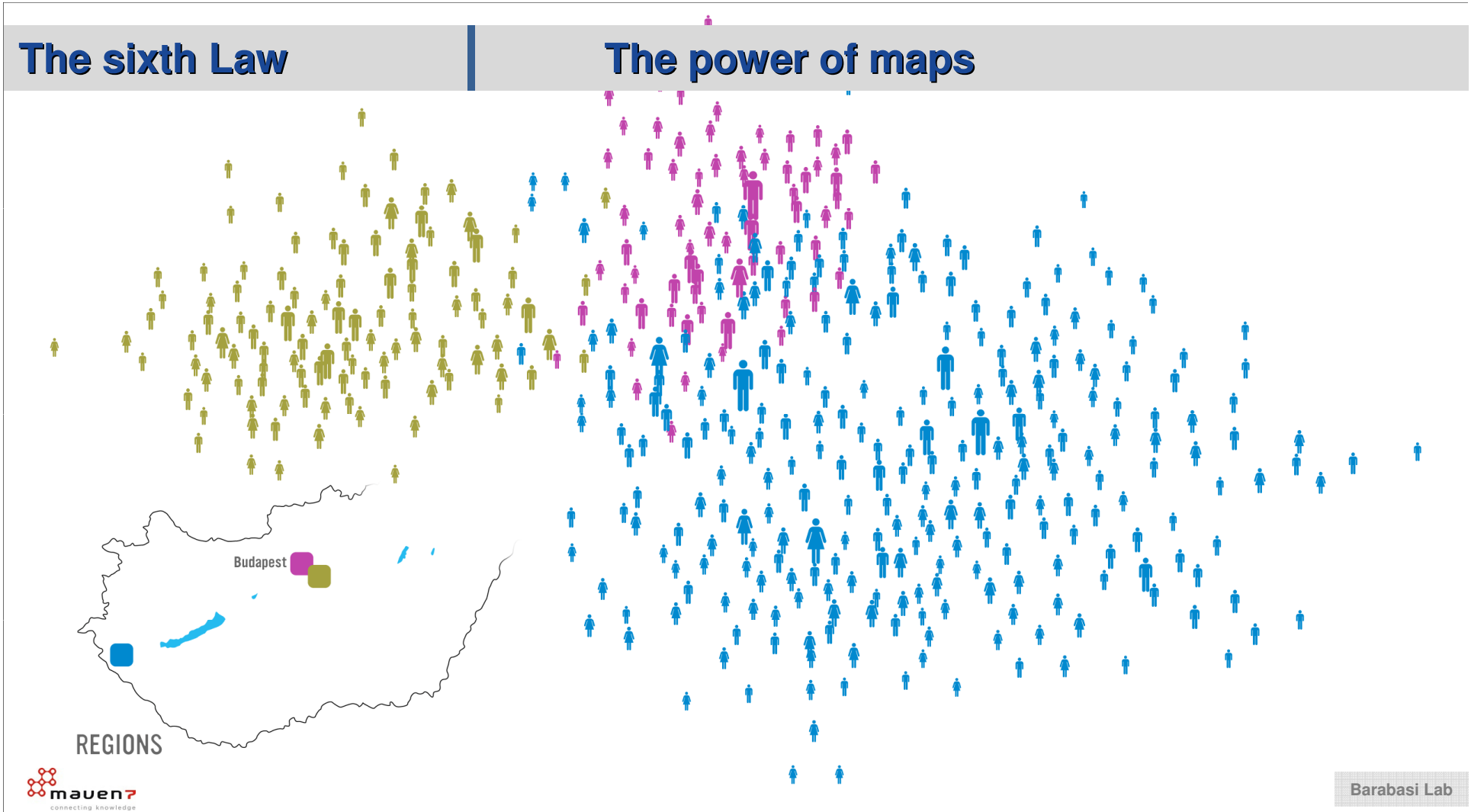
The X's Law

Nodes in the same module have similar dynamics



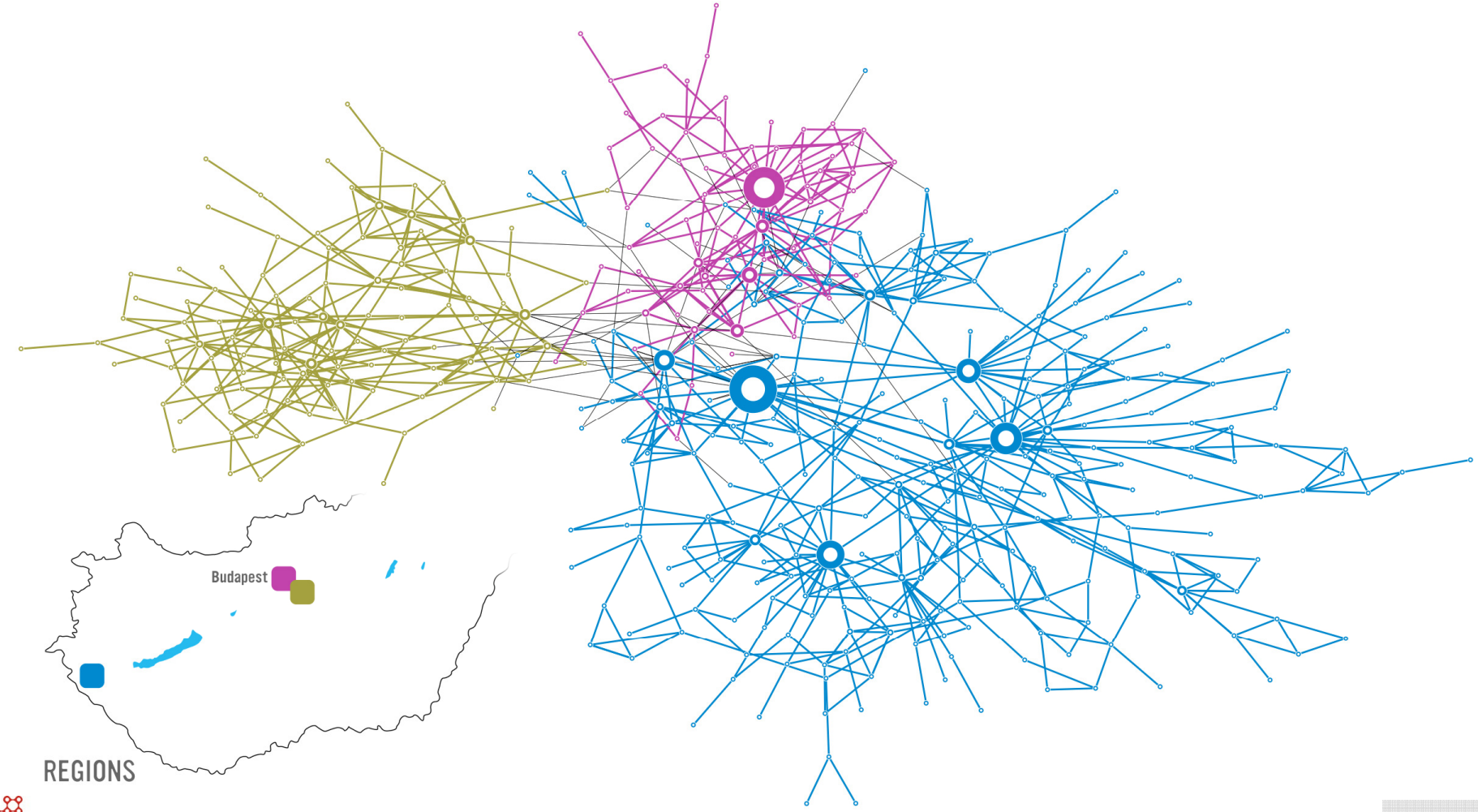
The sixth Law

The power of maps



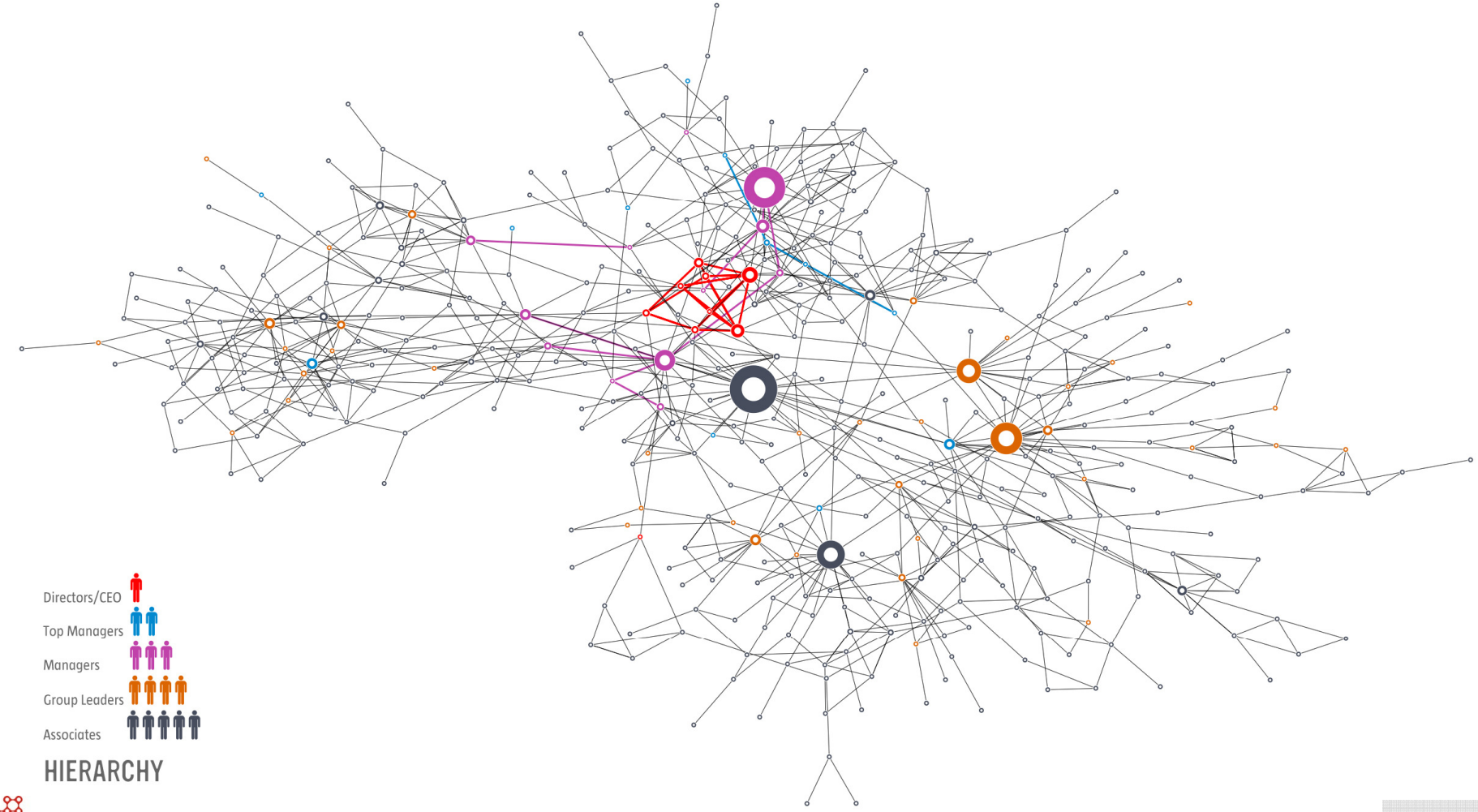
maven7
connecting knowledge

Barabasi Lab



maven7
connecting knowledge

Barabasi Lab

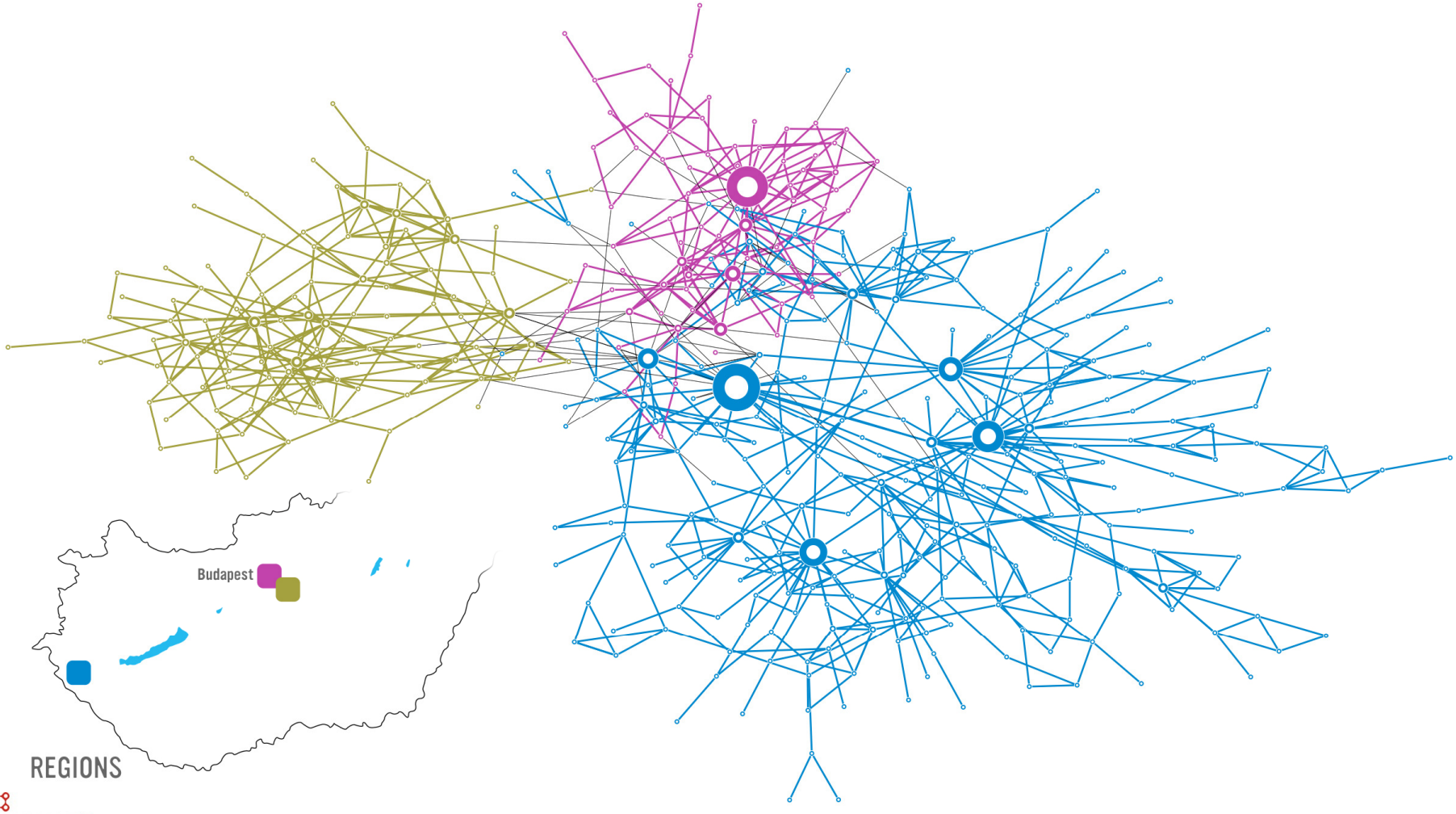


maven7
connecting knowledge

Barabasi Lab


1
2
22 LINKS

The seventh Law | Controllability

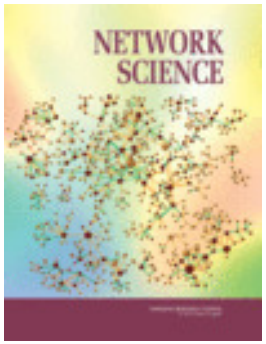


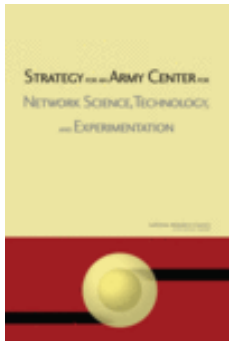
mauen7
connecting knowledge

WHAT IS "NETWORK SCIENCE"?

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

NRC Panel on "Network Science"





An attempt to understand networks emerging in nature, technology and society using a unified set of tools and principles.

What is new here?

Despite the apparent differences, many networks emerge and evolve driven by a fundamental set of laws and mechanism.

BONUS: WHY KEVIN BACON?

Measure the average distance between Kevin Bacon and all other actors.

Kevin Bacon

No. of movies : 46
No. of actors : 1811
Average separation: 2.79

Is Kevin Bacon the most connected actor?

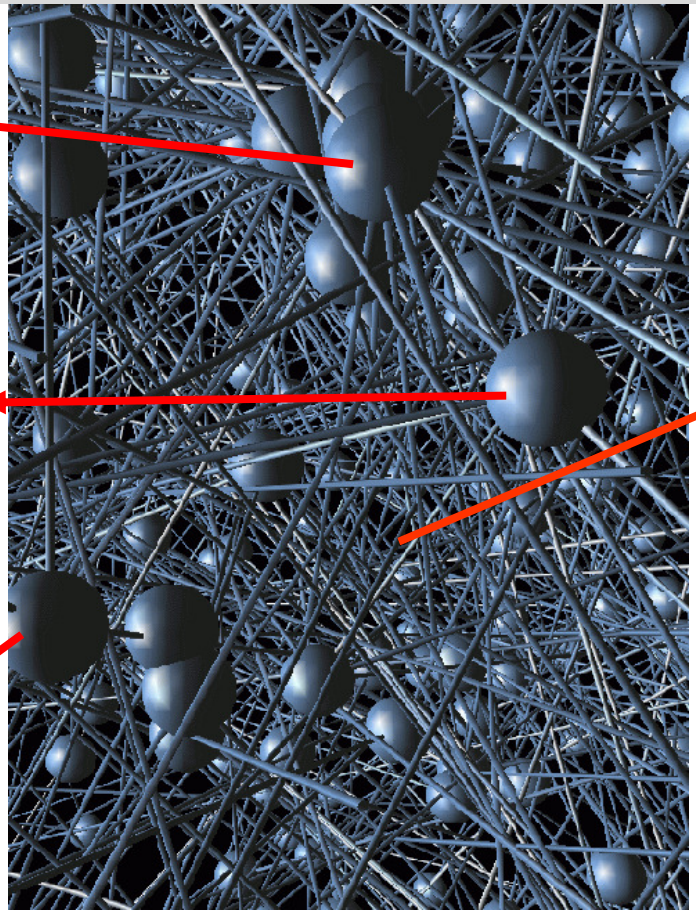
Rank	Name	Average distance	# of movies	# of links
1	Rod Steiger	2.537527	112	2562
2	Donald Pleasence	2.542376	180	2874
3	Martin Sheen	2.551210	136	3501
4	Christopher Lee	2.552497	201	2993
5	Robert Mitchum	2.557181	136	2905
6	Charlton Heston	2.566284	104	2552
7	Eddie Albert	2.567036	112	3333
8	Robert Vaughn	2.570193	126	2761
9	Donald Sutherland	2.577880	107	2865
10	John Gielgud	2.578980	122	2942
11	Anthony Quinn	2.579750	146	2978
12	James Earl Jones	2.584440	112	3787
…				
876	Kevin Bacon	2.786981	46	1811
…				

KEVIN BACON MAP

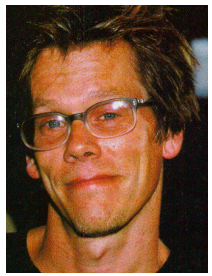
1
Rod Steiger

2
Donald Pleasence

3
Martin Sheen



876
Kevin Bacon

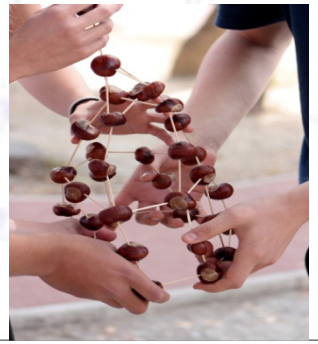


FuturICT.hu: Társadalmi Megújulás Operatív Program szakember utánpótlás biztosítására

Ösztöndíj gyakorló pedagógusok számára 2013-14 időszakra:

Hálózatok gyerek-szemmel témában:

- féléves szakköri tanmenet
- fakultációs óra-terv
- csoportos foglalkozások
- problémamegoldó versenyek



Network Science

an interactive textbook

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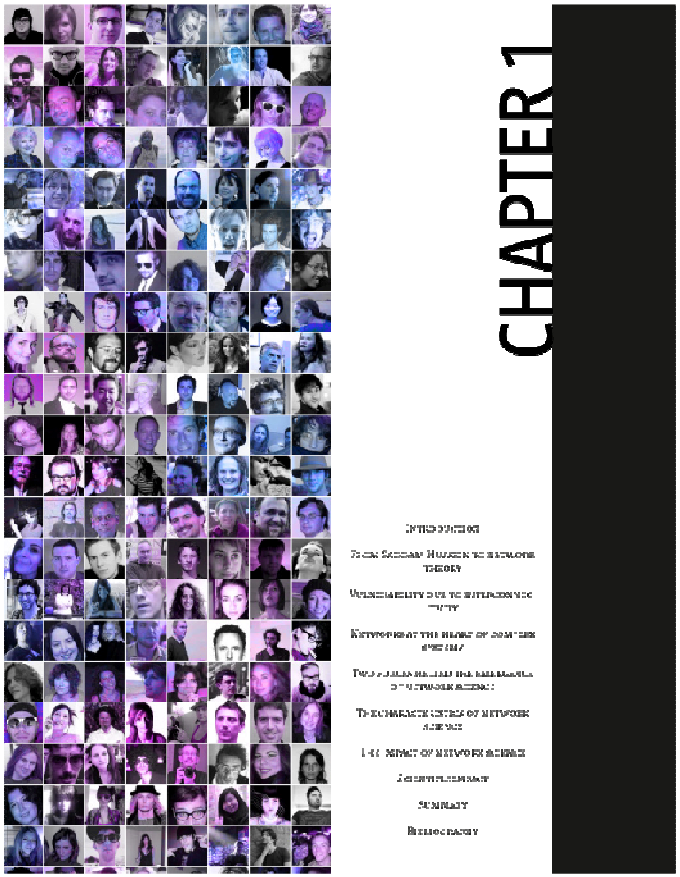
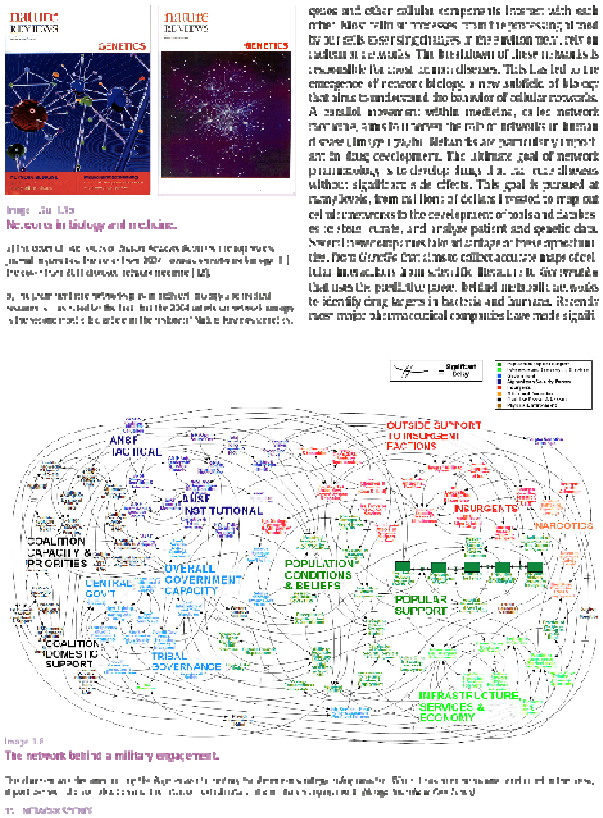


CHAPTER 1



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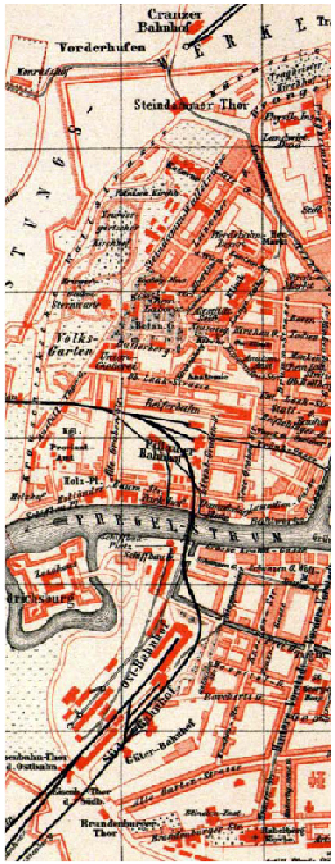
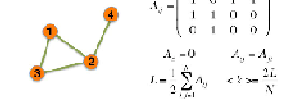


CHAPTER 2

Graphology

Undirected



$$A_{ij} = \begin{pmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$A_{ii} = 0 \qquad A_{ij} = A_{ji}$$

$$L = \frac{1}{2}\sum_{i,j=1}^{N} A_{ij} \qquad \langle k \rangle = \frac{2L}{N}$$

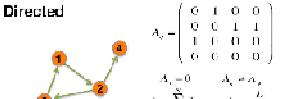
Self-interactions

$$A_{ij} = \begin{pmatrix} 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix}$$

$$A_{ii} \neq 0 \qquad A_{ij} = A_{ji}$$

$$L = \frac{1}{2}\sum_{i,j=1}^{N} A_{ij} - \sum_{i=1}^{N} A_{ii} \qquad ?$$

Directed

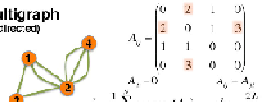


$$A_{ij} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

$$A_{ii} = 0 \qquad A_{ij} \neq A_{ji}$$

$$L = \sum_{i,j=1}^{N} A_{ij} \qquad \langle k \rangle = \frac{L}{N}$$

Multigraph
(unchecked)

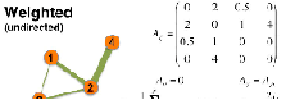


$$A_{ij} = \begin{pmatrix} 0 & 2 & 1 & 0 \\ 2 & 0 & 1 & 3 \\ 1 & 1 & 0 & 0 \\ 0 & 3 & 0 & 0 \end{pmatrix}$$

$$A_{ii} = 0 \qquad A_{ij} = A_{ji}$$

$$L = \frac{1}{2}\sum_{i,j=1}^{N} A_{ij} \qquad \langle k \rangle = \frac{2L}{N}$$

Weighted
(undirected)

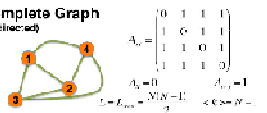


$$A_{ij} = \begin{pmatrix} 0 & 2 & 0.5 & 0 \\ 2 & 0 & 1 & 4 \\ 0.5 & 1 & 0 & 0 \\ 0 & 4 & 0 & 0 \end{pmatrix}$$

$$A_{ii} = 0 \qquad A_{ij} = A_{ji}$$

$$L = \frac{1}{2}\sum_{i,j=1}^{N} A_{ij} \qquad \langle k \rangle = \frac{2L}{N}$$

Complete Graph
(undirected)



$$A_{ij} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$

$$A_{ii} = 0 \qquad A_{ij} = 1$$

$$L = L_{max} = \frac{N(N-1)}{2} \qquad \langle k \rangle = N - 1$$

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