

**A hálózatok világában**

**Barabási Albert-László**

CENTER FOR COMPLEX NETWORKS RESEARCH

NORTHEASTERN UNIVERSITY

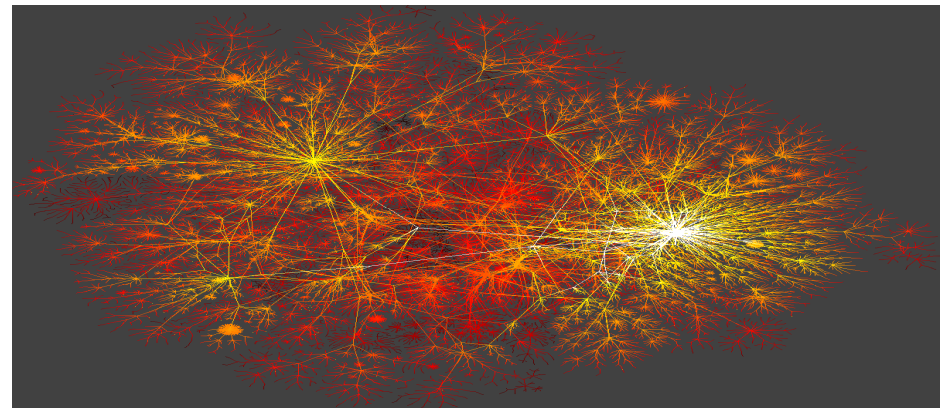
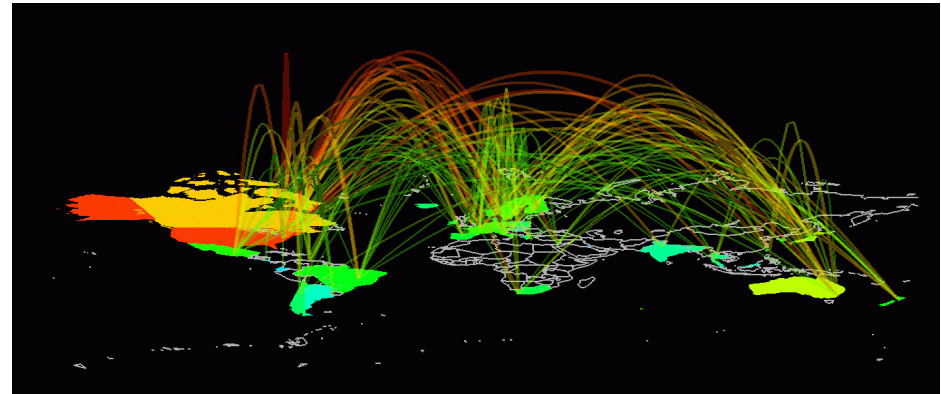
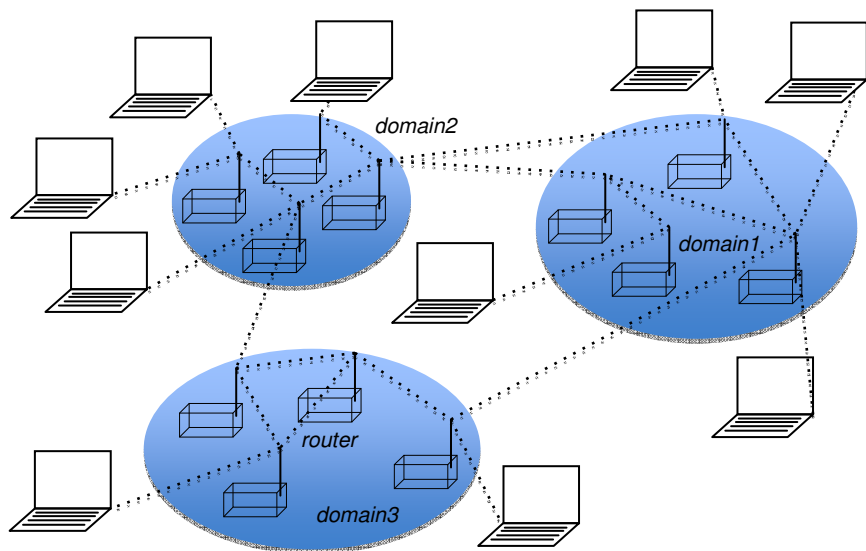
DEPARTMENT OF MEDICINE AND CCSB

HARVARD MEDICAL SCHOOL

CENTRAL EUROPEAN UNIVERSITY, BUDAPEST

[www.BarabasiLab.com](http://www.BarabasiLab.com)

# INTERNET



**SOCIETY**

## Facebook: The Social Graph

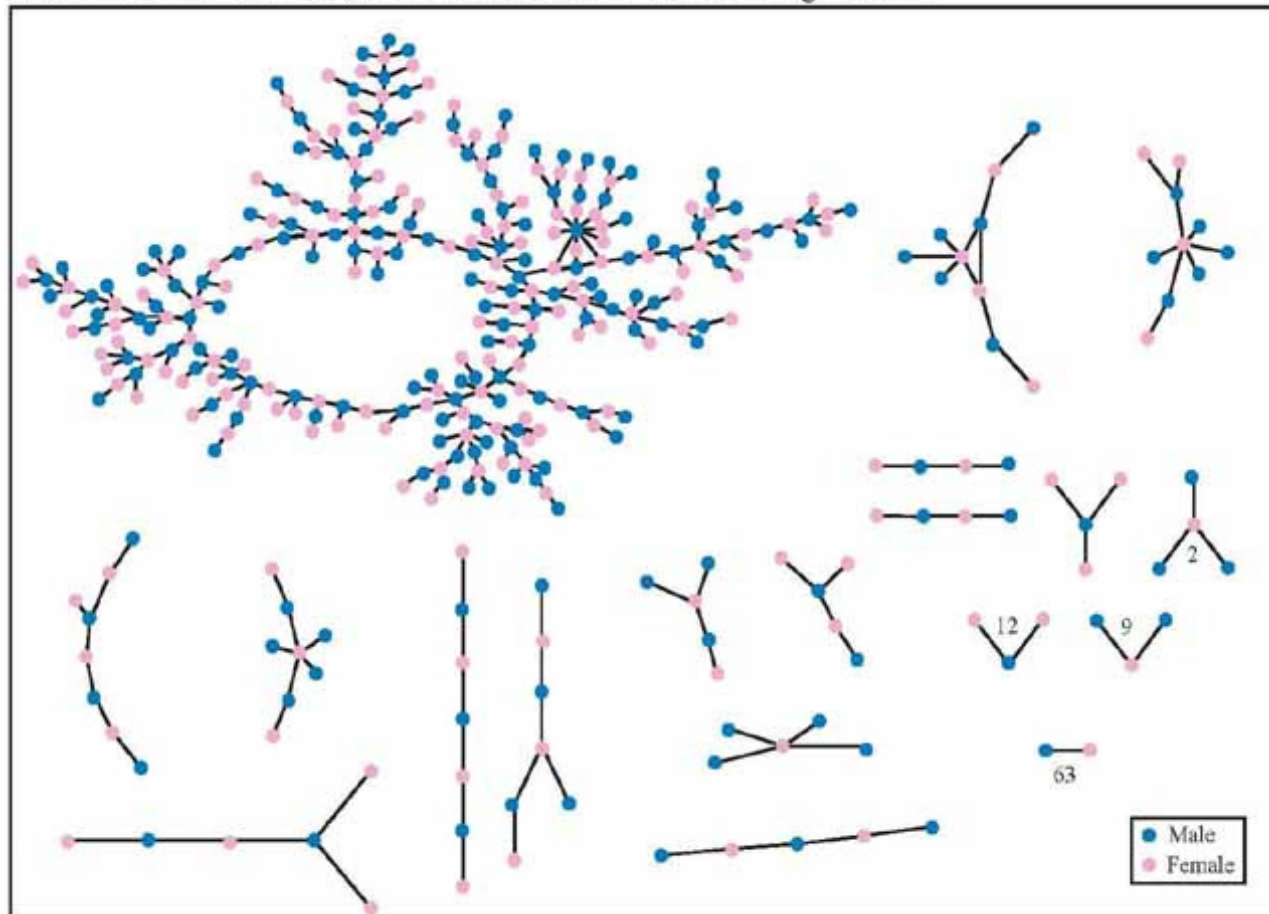


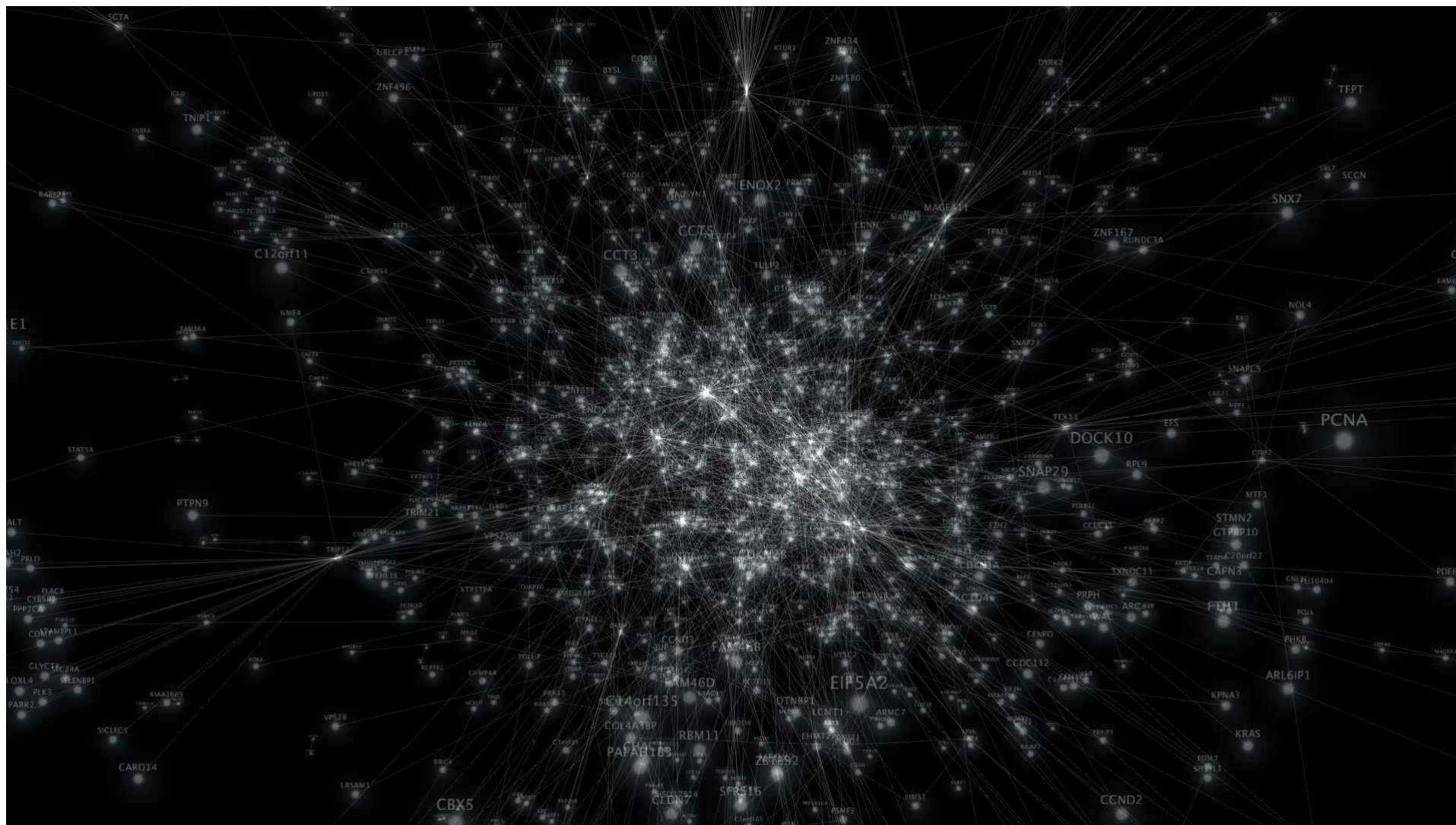
*Keith Shepherd's "Sunday Best". <http://baseballart.com/2010/07/shades-of-greatness-a-story-that-needed-to-be-told/>*

**Southampton, Network Science: Introduction** *July 15, 2011*

# HIGH SCHOOL ROMANTIC NETWORKS

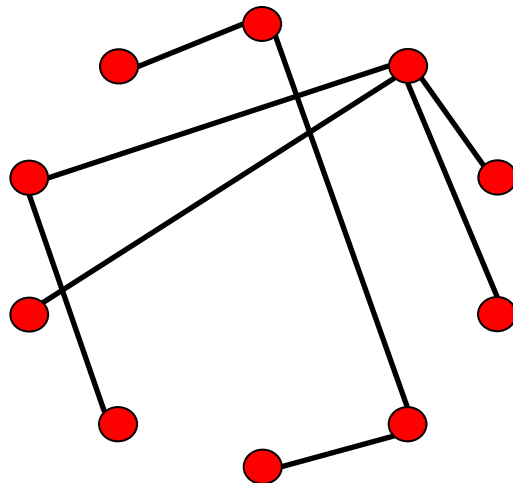
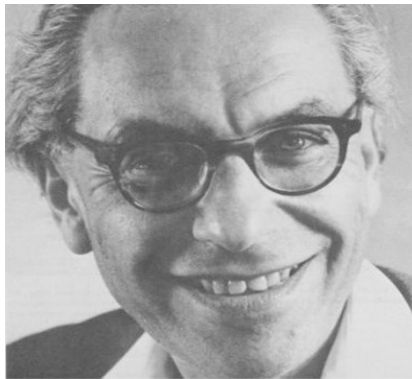
The Structure of Romantic and Sexual Relations at "Jefferson High School"





# RANDOM NETWORK MODEL

**Pál Erdős**  
(1913-1996)

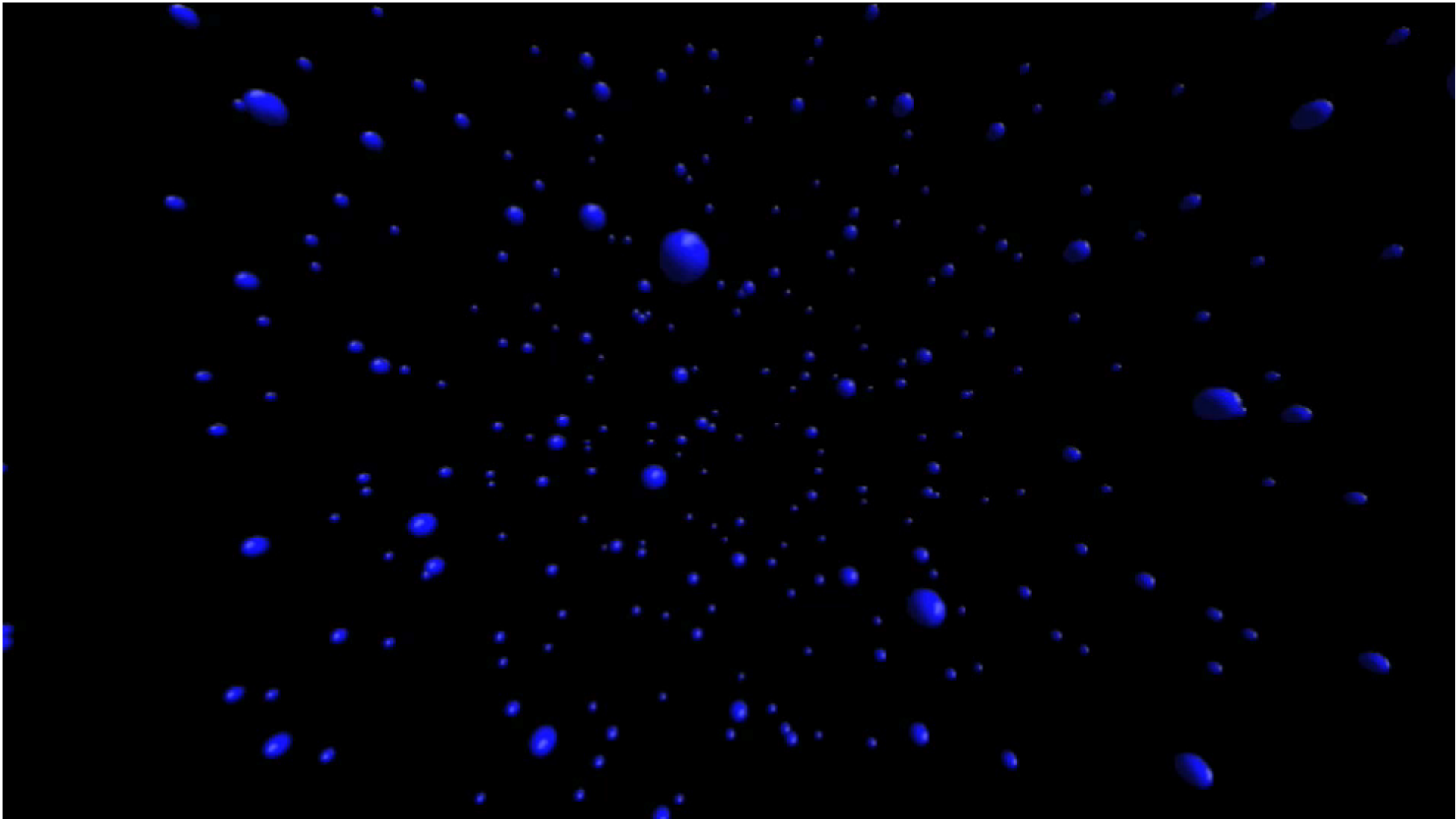


**Erdős-Rényi model (1960)**

**Connect with probability  $p$**

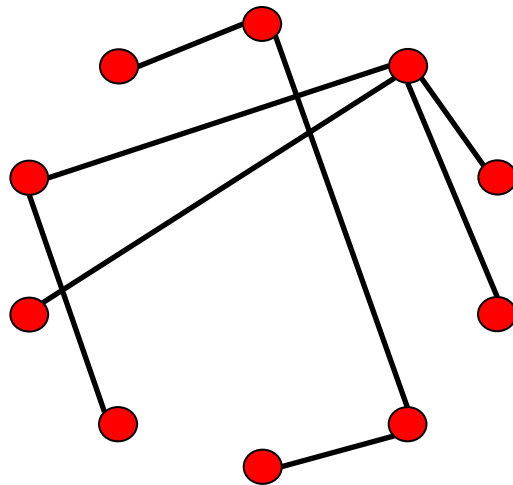
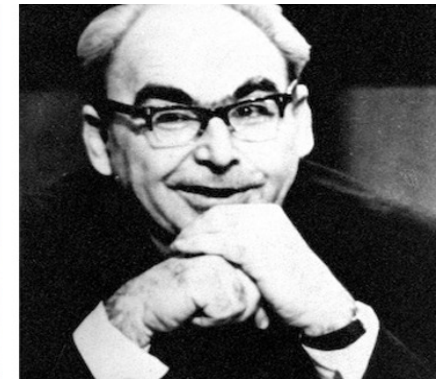
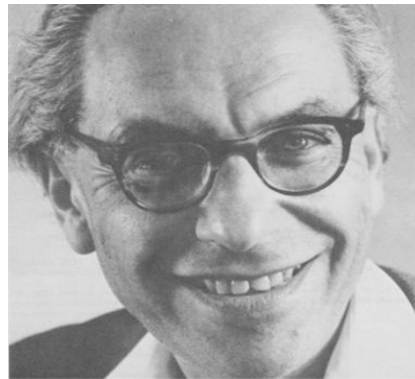
$$p = 1/6 \quad N = 10$$

$$\langle k \rangle \sim 1.5$$



# RANDOM NETWORK MODEL

**Pál Erdős**  
(1913-1996)



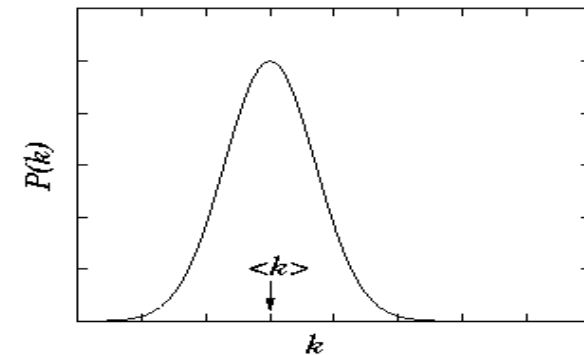
## Erdős-Rényi model (1960)

Connect with probability  $p$

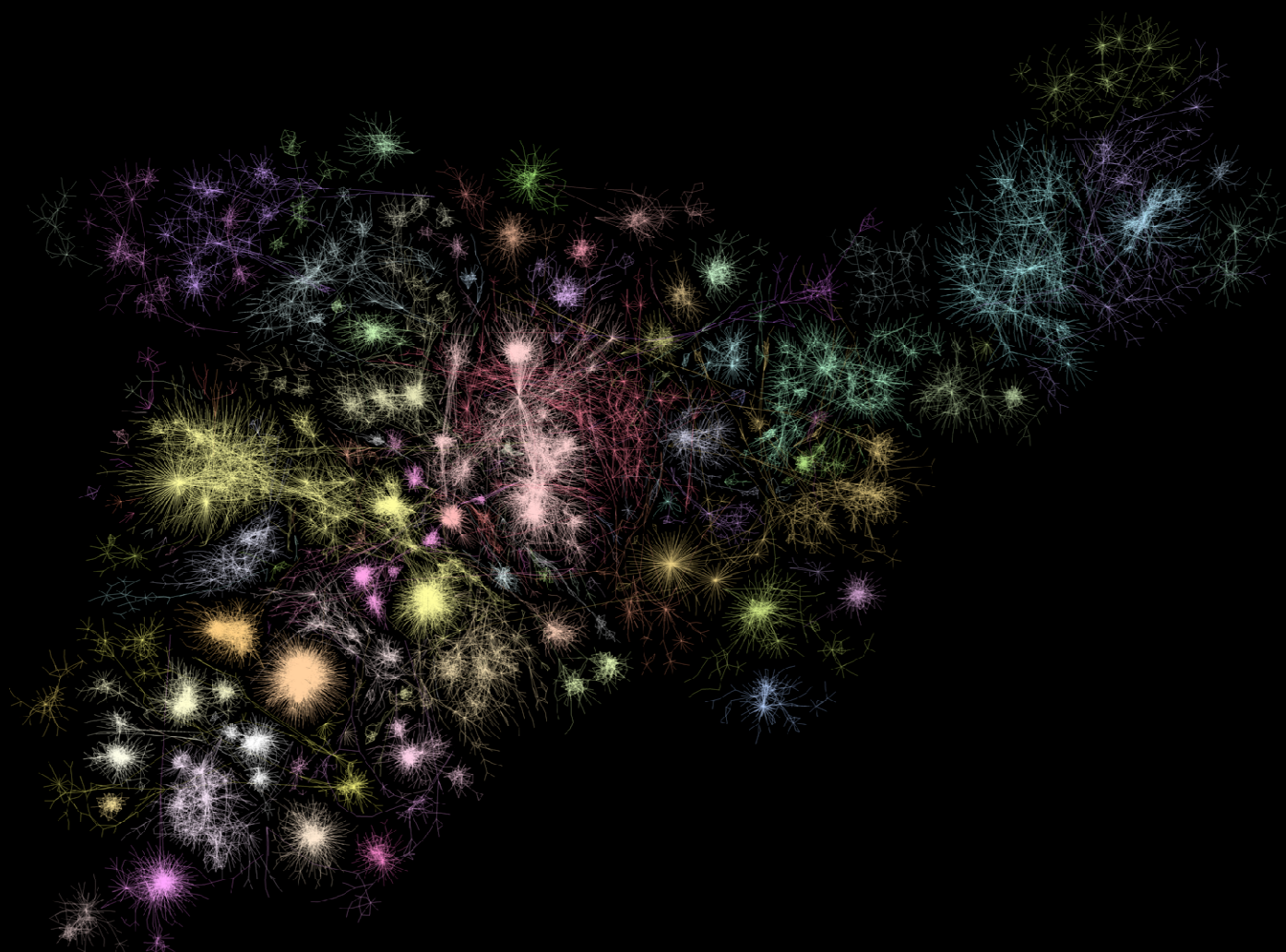
$$p = 1/6 \quad N = 10$$

$$\langle k \rangle \sim 1.5$$

## Degree distribution





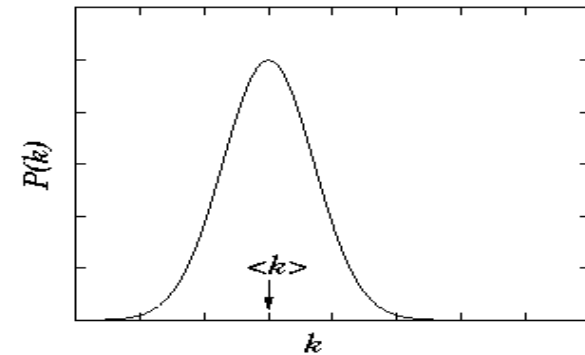


<http://www.race.u-tokyo.ac.jp/~uchida/blogdata/>

Southampton, Network Science: Introduction July 15, 2011

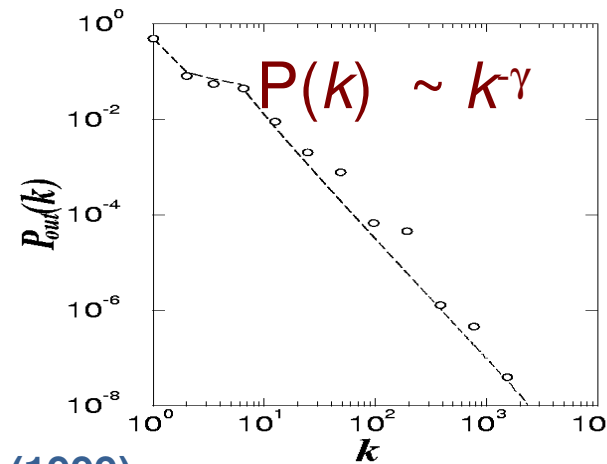
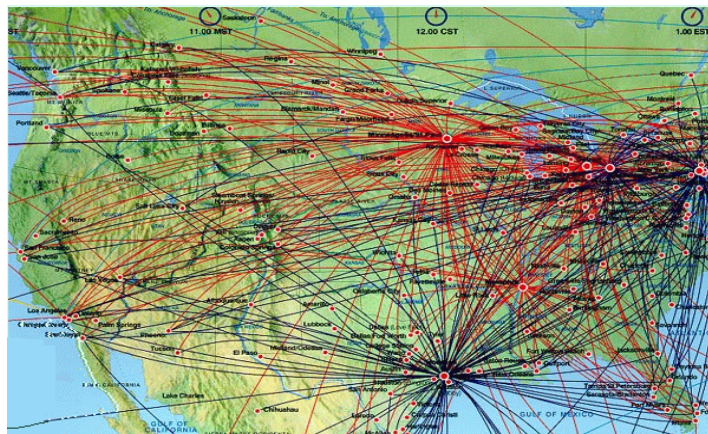
# WORLD WIDE WEB

Random  
Network



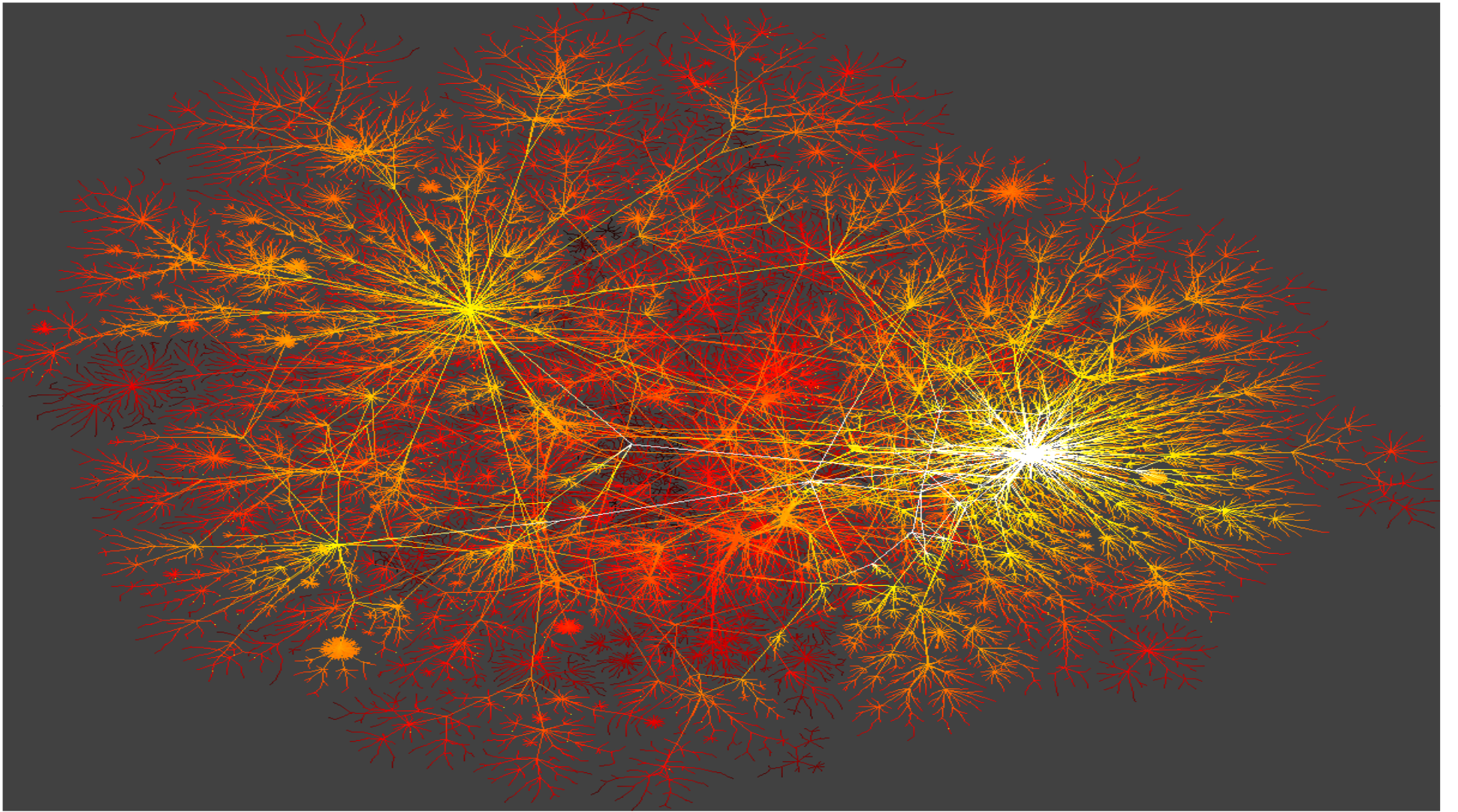
Expected

Scale-free  
Network



Found

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



# ACTOR NETWORK

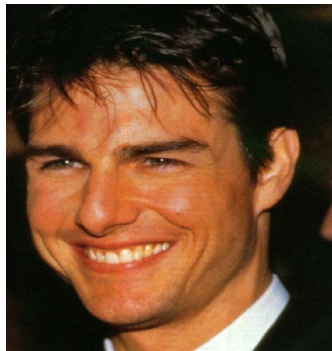


Austin Powers:  
The spy who  
shagged me



Robert Wagner

Wild Things



A Few  
Good Men



Let's make  
it legal



What Price Glory

Barry Norton

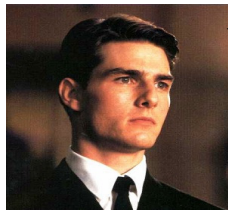


Monsieur  
Verdoux



# ACTOR NETWORK

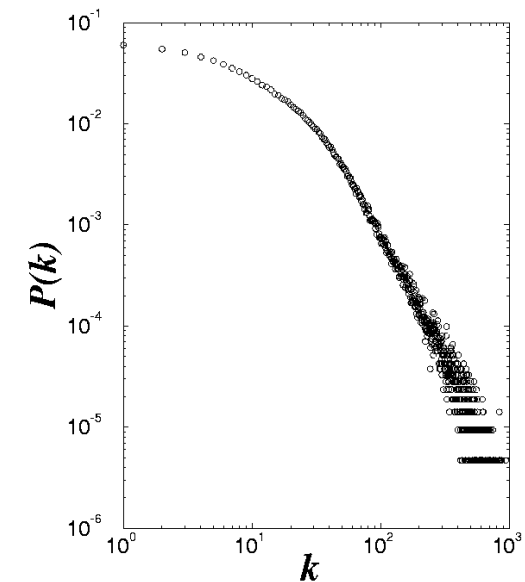
Nodes: actors  
Links: cast jointly



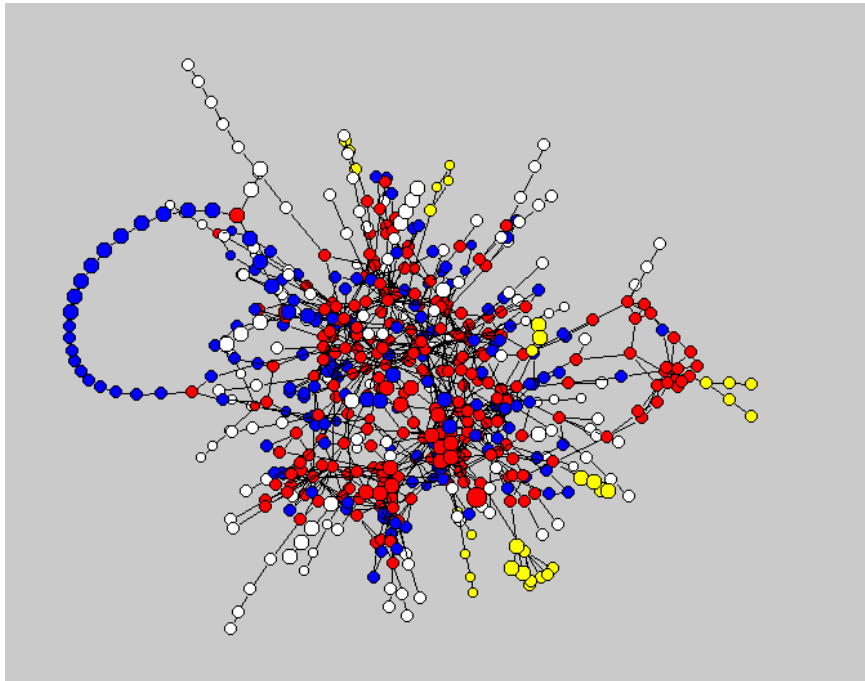
Days of Thunder (1990)  
Far and Away (1992)  
Eyes Wide Shut (1999)



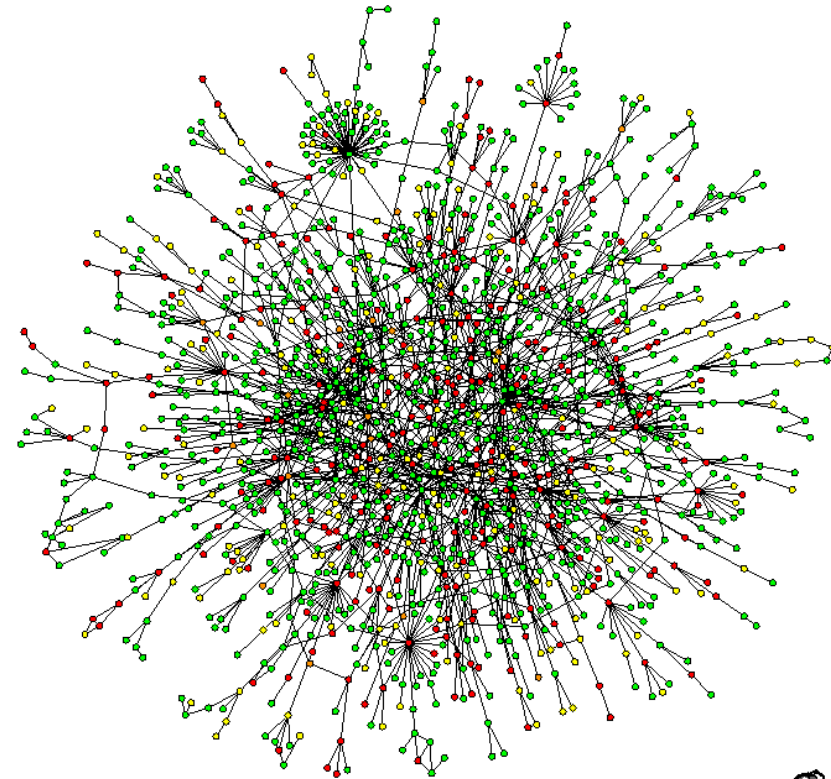
$N = 212,250$  actors     $\langle k \rangle = 28.78$      $P(k) \sim k^{-\gamma}$   
 $\gamma = 2.3$



## METABOLIC NETWORK

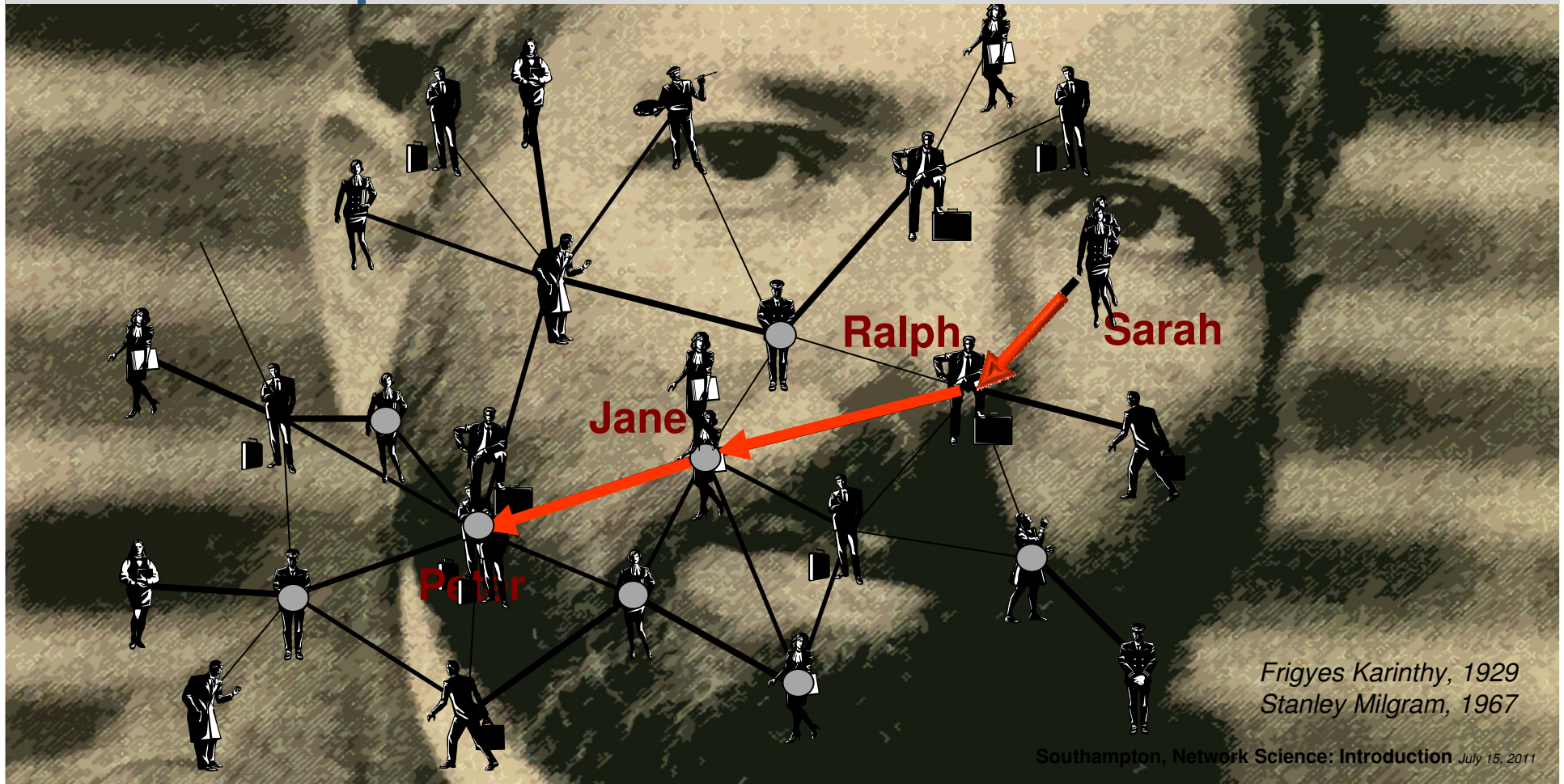


## PROTEIN INTERACTIONS



# 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 létesíteni 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...

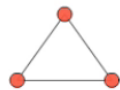
## ORIGIN OF SF NETWORKS: Growth and preferential attachment

(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



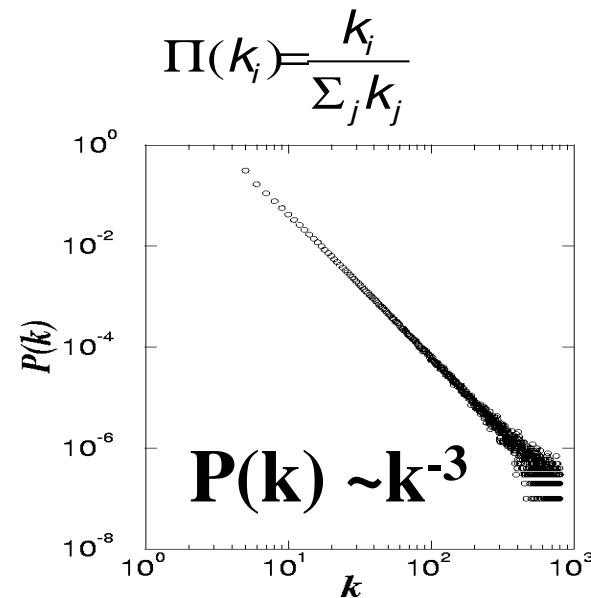
Barabási & Albert, *Science* **286**, 509 (1999)

**GROWTH:**

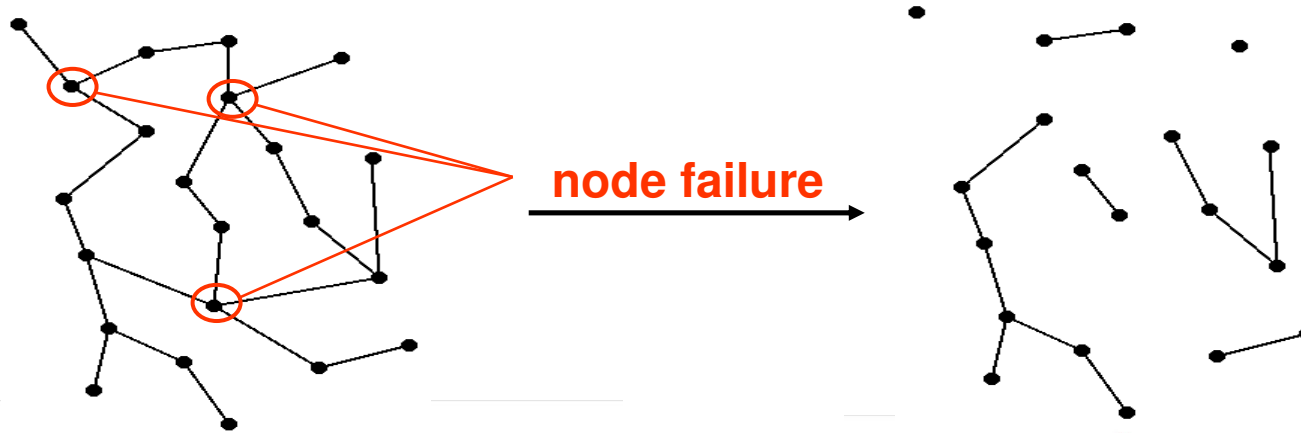
add a new node with  $m$  links

**PREFERENTIAL ATTACHMENT:**

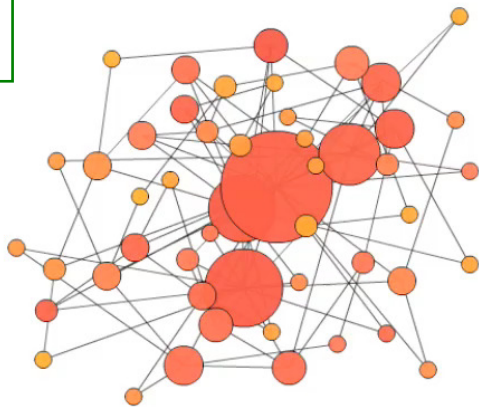
the probability that a node connects to a node with  $k$  links is proportional to  $k$ .



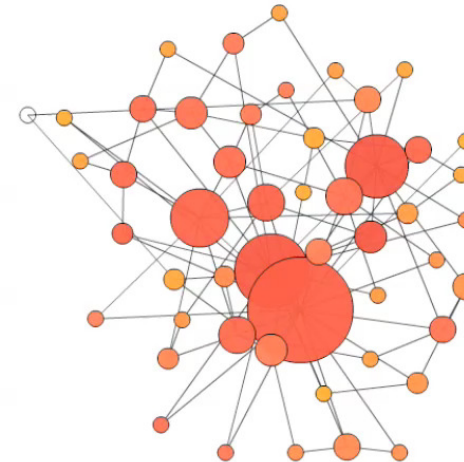
# ROBUSTNESS OF SCALE-FREE NETWORKS



Failures



Attacks

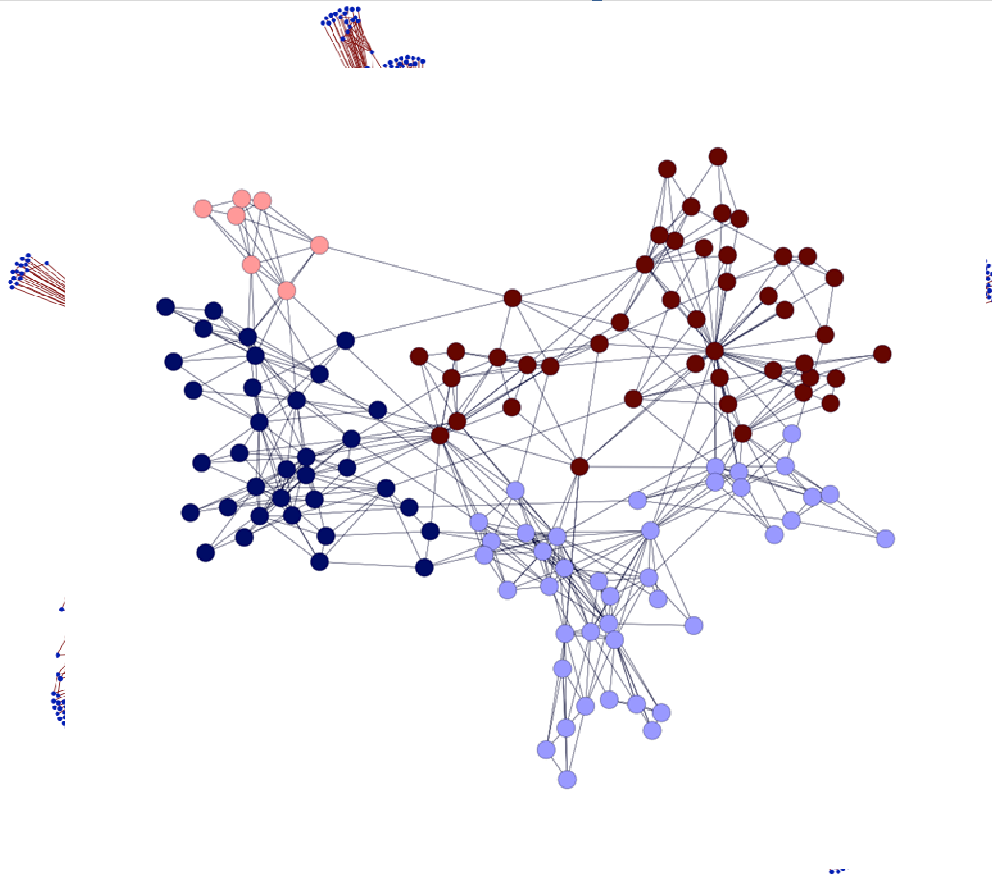


Albert, Jeong, Barabási, *Nature* 406 378 (2000)

Southampton, Network Science: Introduction July 15, 2011

## The X's Law

## Nodes form communities

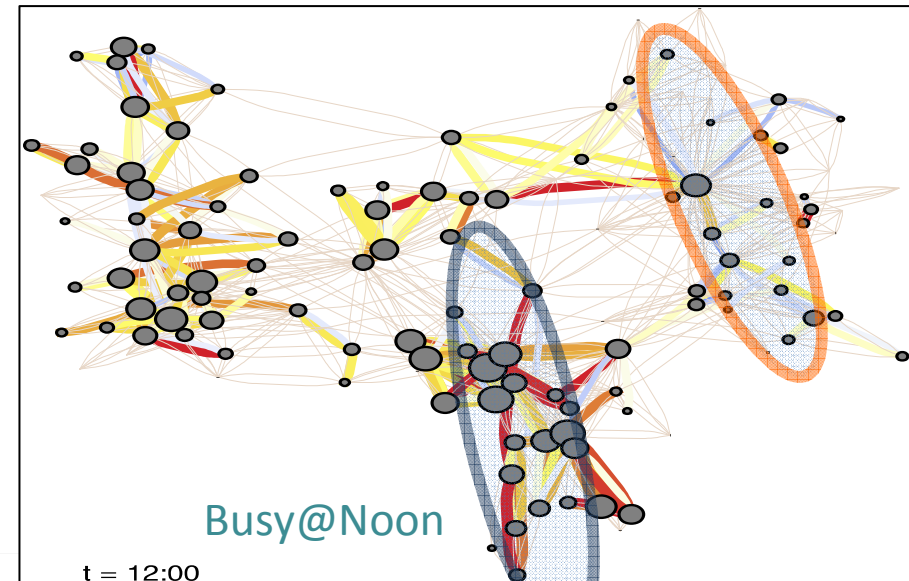
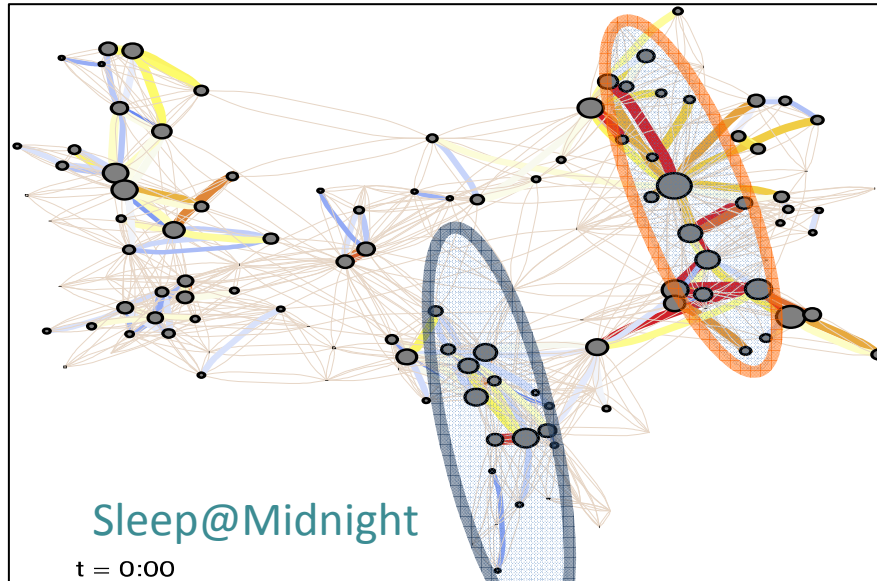


# The X's Law

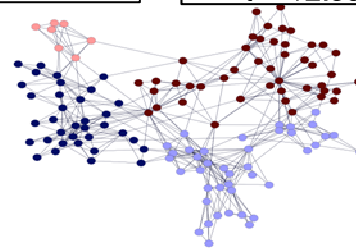
Nodes in the same module have similar dynamics

Busy@Midnight

Sleep@Noon



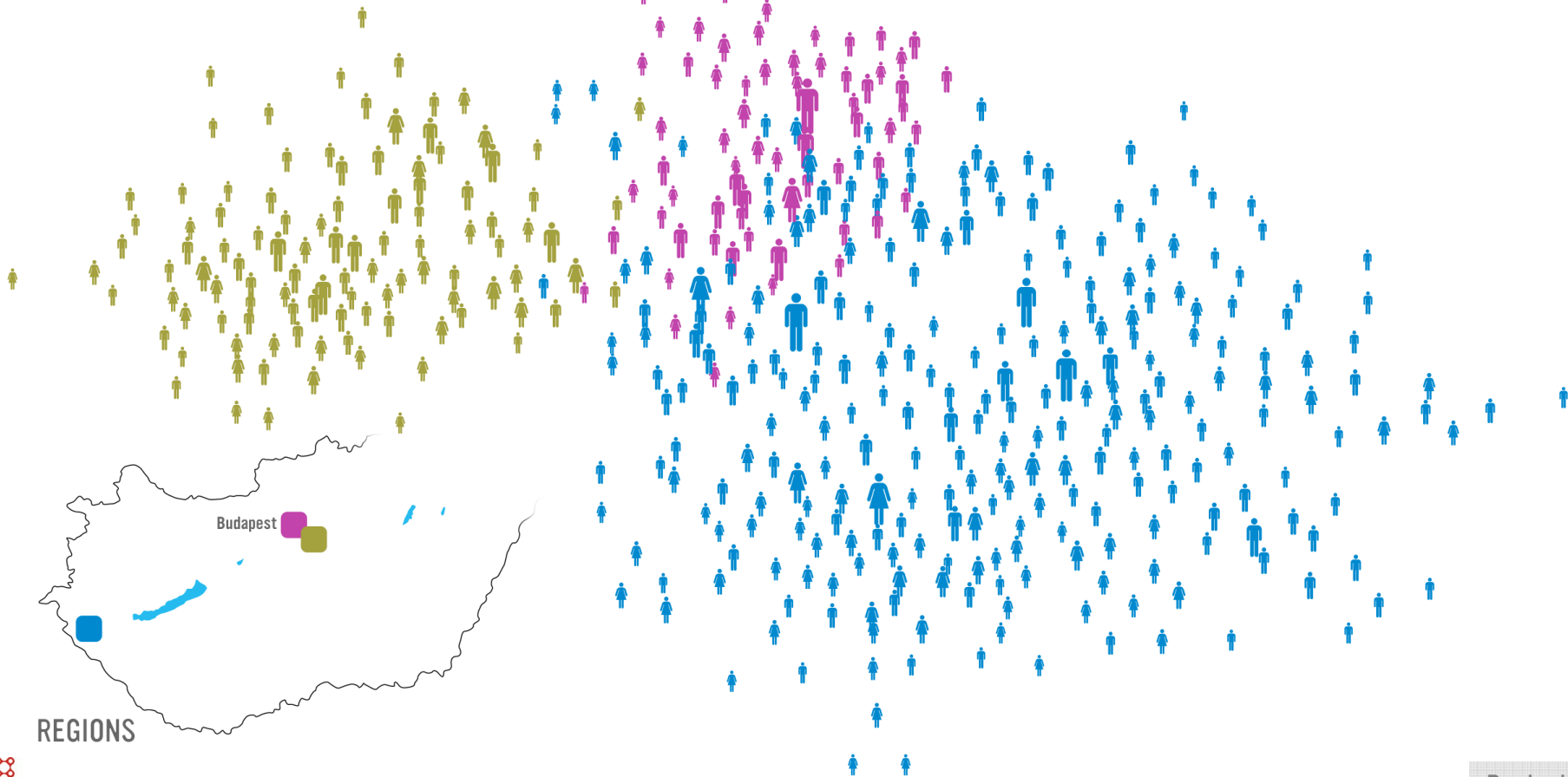
Midnight

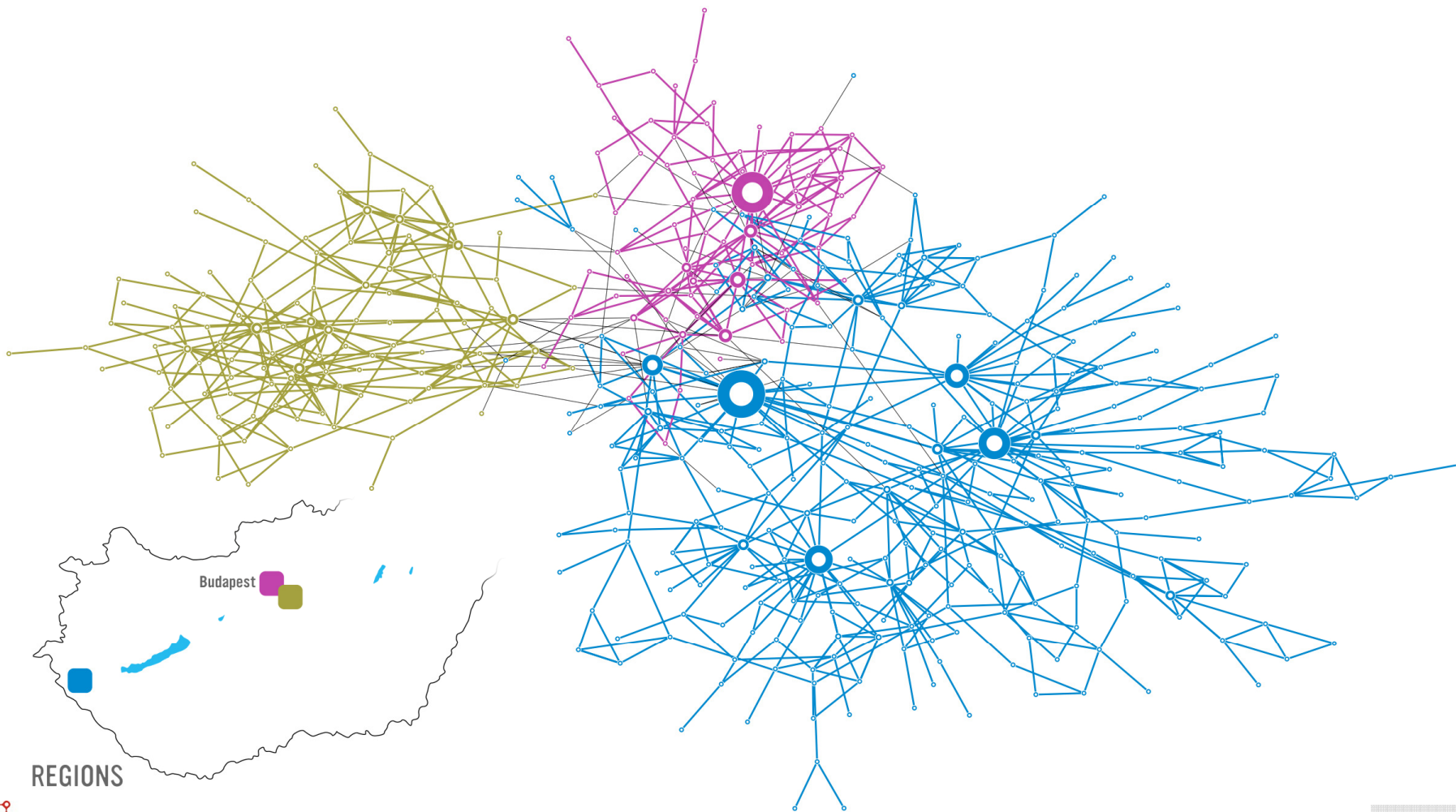


Noon

## The sixth Law

## The power of maps

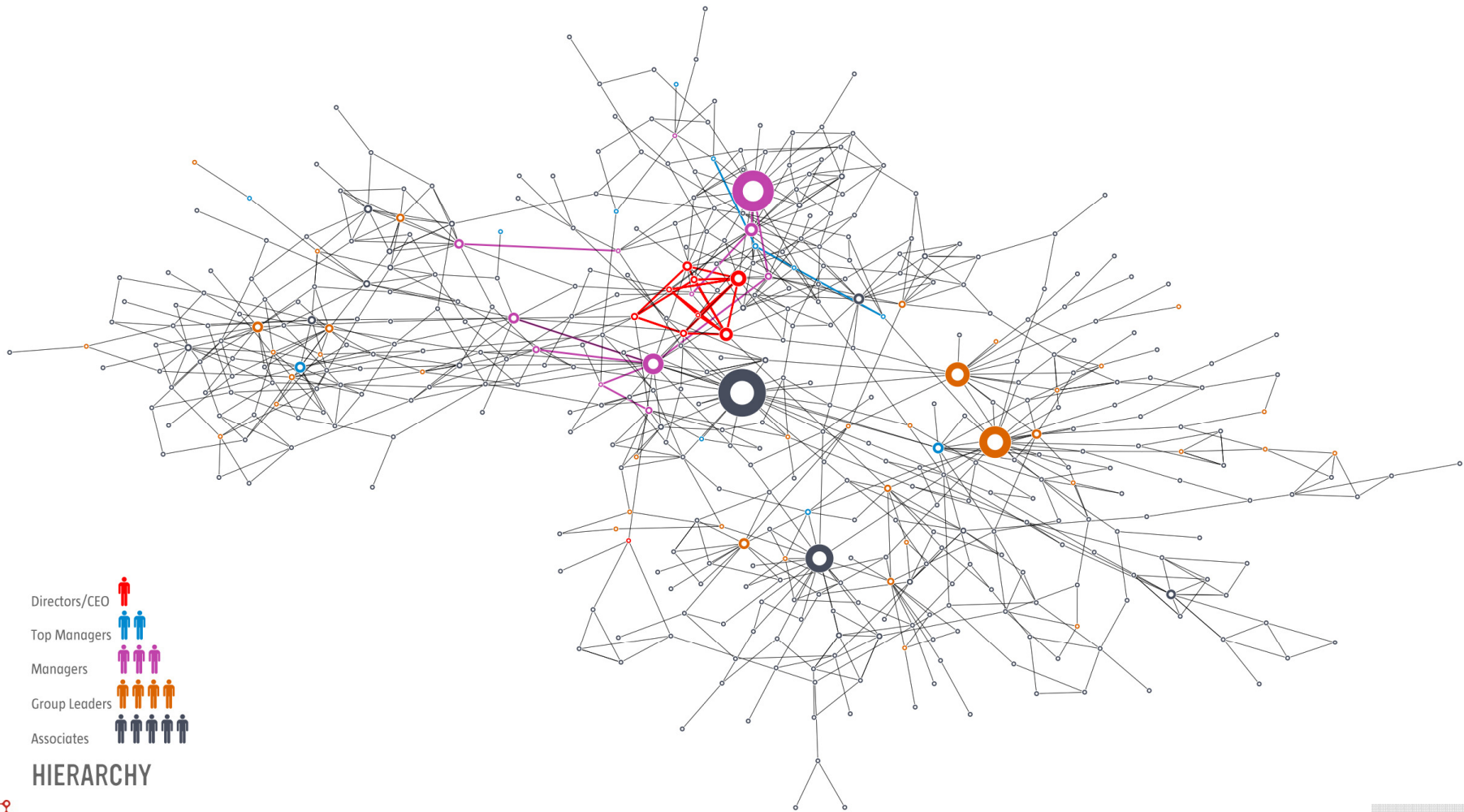




REGIONS



Barabasi Lab



- Directors/CEO 
- Top Managers 
- Managers 
- Group Leaders 
- Associates 

### HIERARCHY



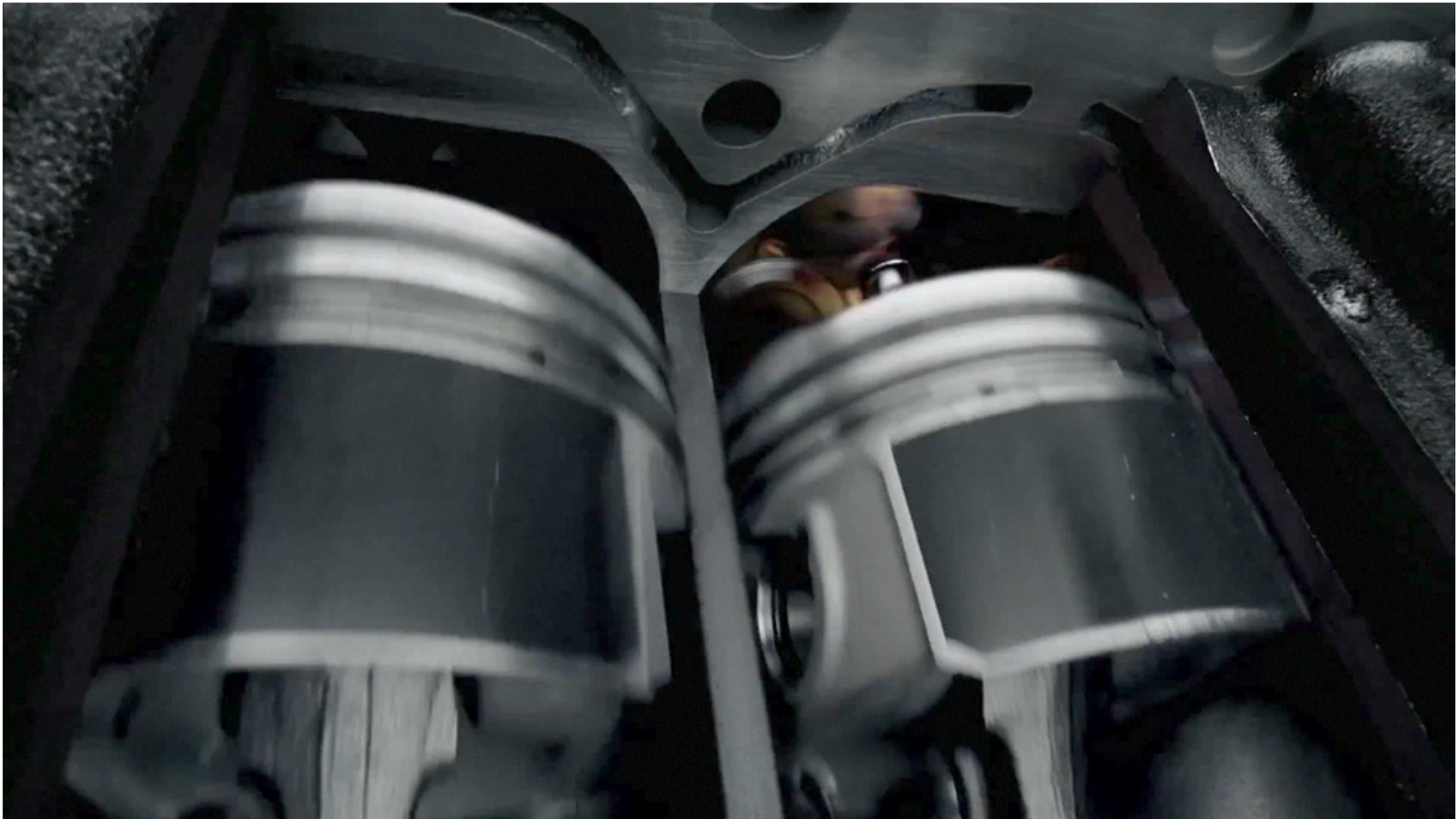


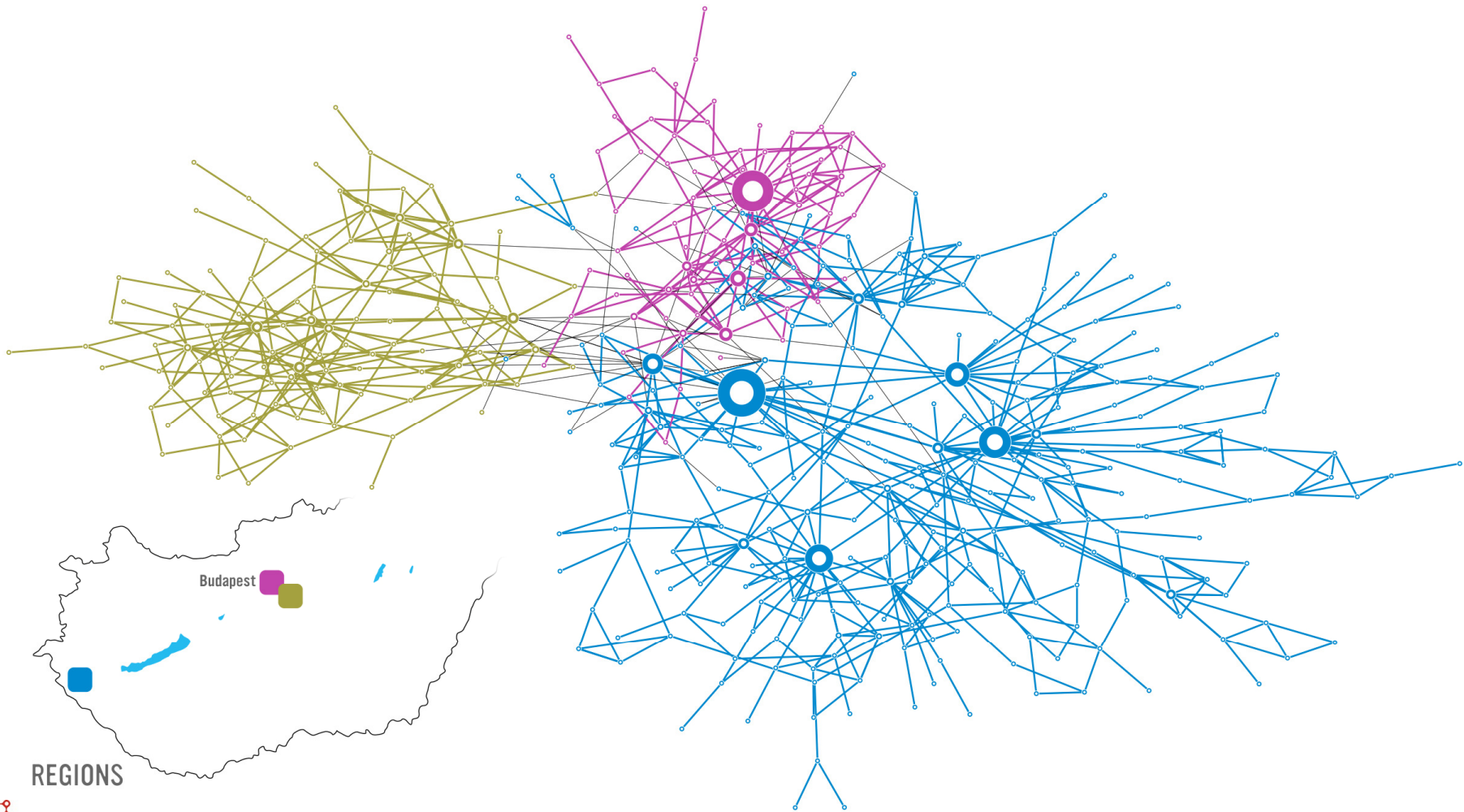


## The seventh Law

## Controllability







Budapest

REGIONS





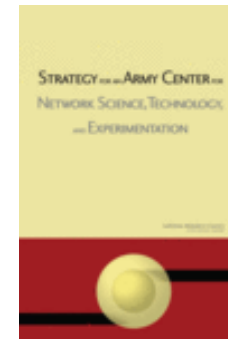
# WHAT IS “NETWORK SCIENCE”?

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

## NRC Panel on “Network Science”

### What is new here?

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



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

## 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



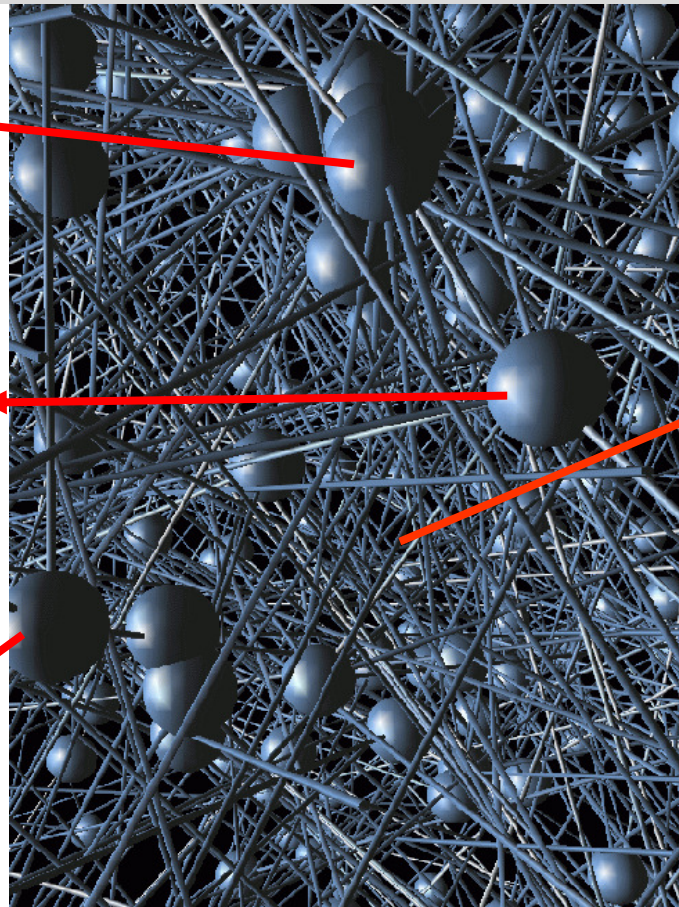
1  
Rod Steiger



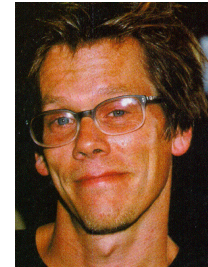
2  
Donald Pleasence

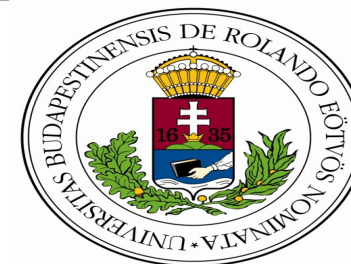


3  
Martin Sheen



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



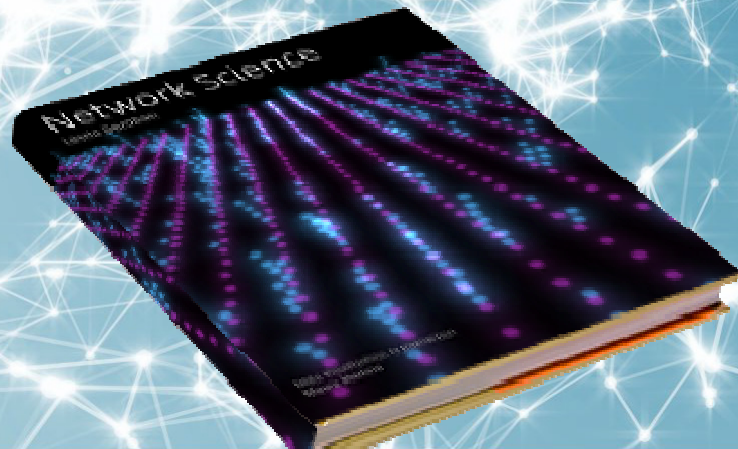
# Network Science

an interactive textbook



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[facebook.com/NetworkScienceBook](https://facebook.com/NetworkScienceBook)



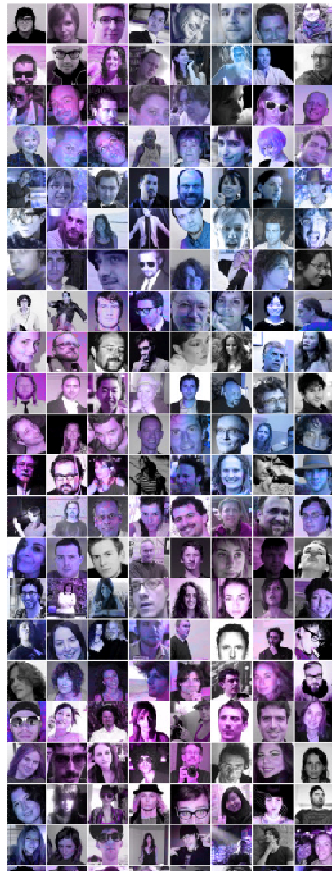
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# CHAPTER 1

- INTRODUCTION
- FROM SCIENCE FICTION TO NETWORK THEORY
- VULNERABILITY DUE TO ENTANGLEMENT
- NETWORKS AT THE HEART OF COMPLEX SYSTEMS
- TWO PILLARS BEHIND THE SCIENCE OF NETWORKS
- THE CHARACTERISTICS OF NETWORK SCIENCE
- THE IMPACT OF NETWORK SCIENCE
- ACKNOWLEDGMENT
- SYNOPSIS
- BIBLIOGRAPHY

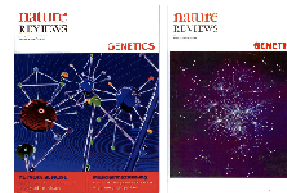


Image 30.10  
Networks in biology and medicine.

At the heart of the science of network science is the study of complex systems. For example, the 2007 genome revolution brought 11 people from different backgrounds together to map the

genome. The network science approach is a natural outgrowth of this work. It is a natural outgrowth of this work. It is a natural outgrowth of this work.

genes and other cellular components interact with each other. Most of our knowledge of the functioning of these biological systems comes from the study of the genome. The breakdown of these interactions is responsible for most genetic diseases. This led to the emergence of network biology, a new subfield of biology that aims to understand the behavior of cellular processes. A similar approach within medicine, called network medicine, aims to uncover the role of networks in human disease development. The ultimate goal of network pharmacology is to develop drugs that treat diseases without significant side effects. This goal is pursued at many levels, from cell lines to clinical research to map out cellular processes to the development of tools and databases on disease, health, and drug pathways and genetic data. Network science can be used to study a broad range of phenomena. From genetic data, network science can be used to study the spread of disease. Network science can be used to study the spread of disease. Network science can be used to study the spread of disease.

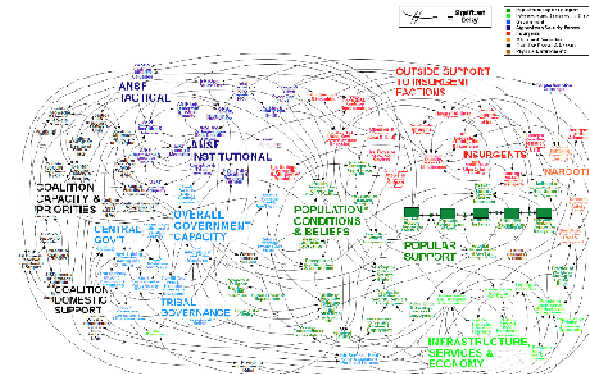


Image 30.9  
The network behind a military engagement.

The diagram shows the network of relationships between various entities involved in a military engagement. The nodes represent different entities, and the edges represent the relationships between them. The network is highly interconnected, with many nodes having multiple connections. The legend indicates that only significant relationships are shown.



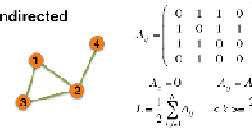
# CHAPTER 2

- THE SCIENCE OF NETWORKS
- NETWORKS AND GRAPHS
- POWER, AVERAGE DEGREE, AND DEGREE DISTRIBUTION
- REAL-NETWORK EFFECTS
- NETWORK ALGEBRA
- WEIGHTS AND CLUSTERING COEFFICIENTS
- FASTEST NETWORKS
- GRAPH REPRESENTATION IN 2D SPACES
- COMMUNITY AND COMPONENTS
- CLUSTERING COEFFICIENT
- CLUSTERS AND HUBS
- OPERATION OF GLOBAL CLUSTERING COEFFICIENT
- REAL-CASE STUDY

## Figure 2.1.6 Graphology

In graph theory, we represent a city or state, an organism, or a computer network as a set of nodes. The connections between nodes are represented by edges. In this section, we explore the relationship between the network and the underlying physical system. We will use the network to model the city of Königsberg, which was a problem for the mathematician Leonhard Euler in 1736. The city was built on an island in the Pregel river, and the problem was to find a path that would cross each of the seven bridges exactly once. This problem is now known as the Königsberg bridge problem.

### Undirected



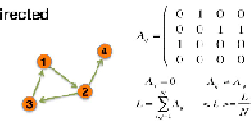
**UNDIRECTED** graphs are symmetric, undirected, and have self-loops. In this example, the nodes are labeled 1, 2, 3, and 4, and the edges are represented by the matrix  $A_{ij}$ .

### Self-Interactions



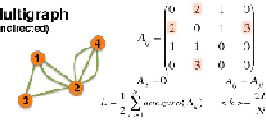
**SELF-INTERACTIONS** are graphs with self-loops. In this example, the nodes are labeled 1, 2, 3, and 4, and the edges are represented by the matrix  $A_{ij}$ . The self-loops are represented by the diagonal elements of the matrix.

### Directed



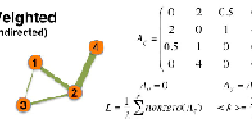
**DIRECTED NETWORKS** are graphs with directed edges. In this example, the nodes are labeled 1, 2, 3, and 4, and the edges are represented by the matrix  $A_{ij}$ .

### Multigraph (undirected)



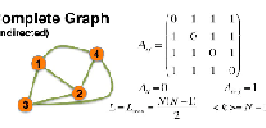
**MULTIGRAPHS** are graphs with multiple edges between nodes. In this example, the nodes are labeled 1, 2, 3, and 4, and the edges are represented by the matrix  $A_{ij}$ .

### Weighted (undirected)



**WEIGHTED NETWORKS** are graphs with weighted edges. In this example, the nodes are labeled 1, 2, 3, and 4, and the edges are represented by the matrix  $A_{ij}$ . The weights are represented by the values in the matrix.

### Complete Graph (undirected)



**COMPLETE GRAPHS** are graphs where every node is connected to every other node. In this example, the nodes are labeled 1, 2, 3, and 4, and the edges are represented by the matrix  $A_{ij}$ .