The Architecture of Complexity:

From Networks to Economic Systems

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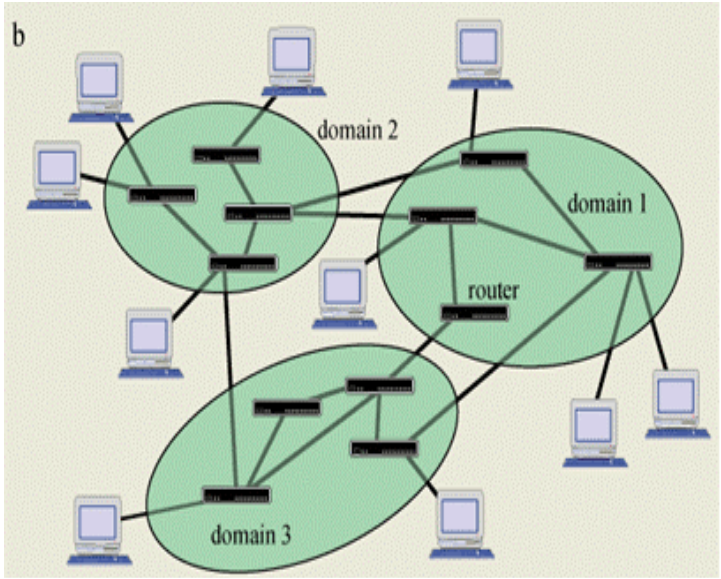
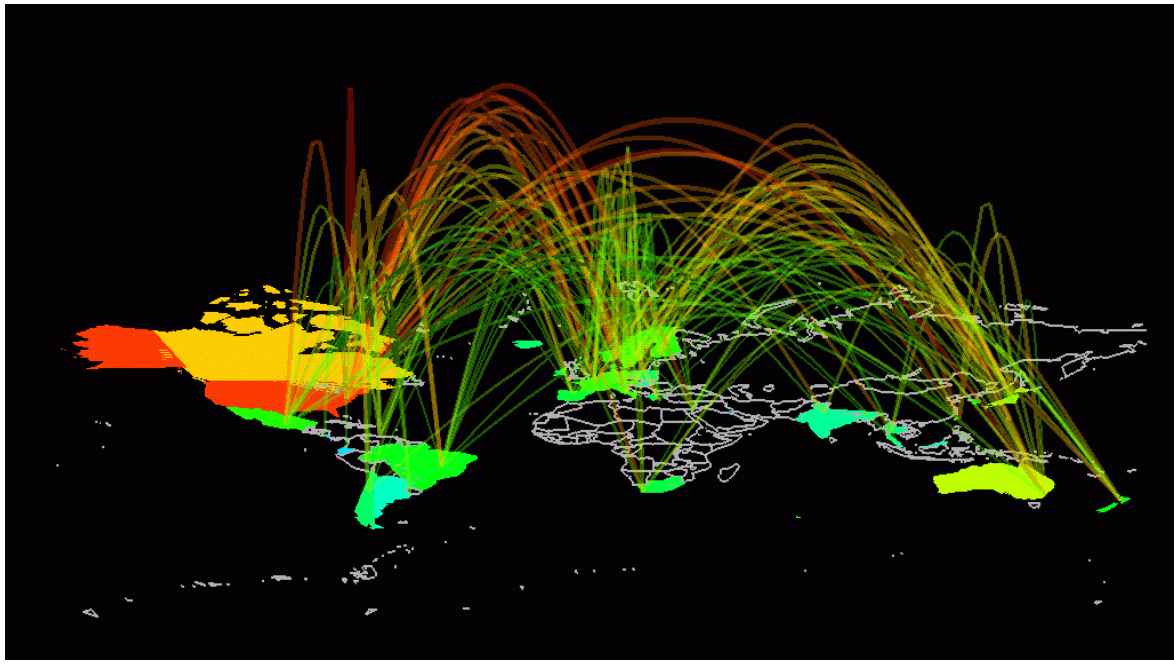
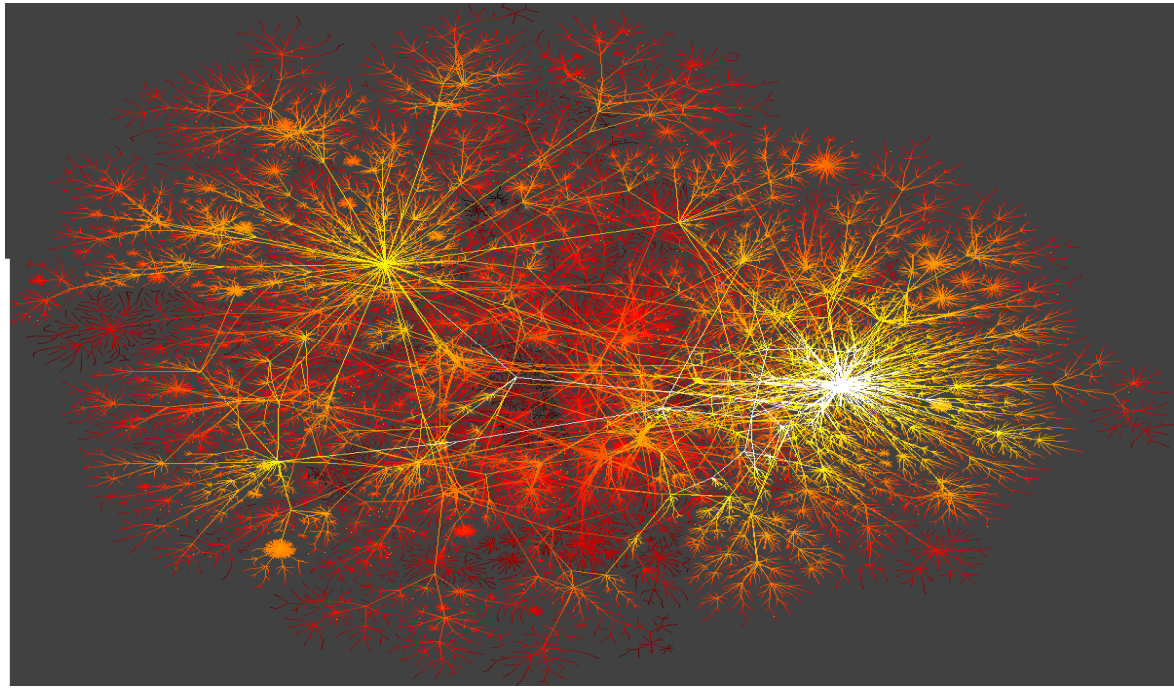
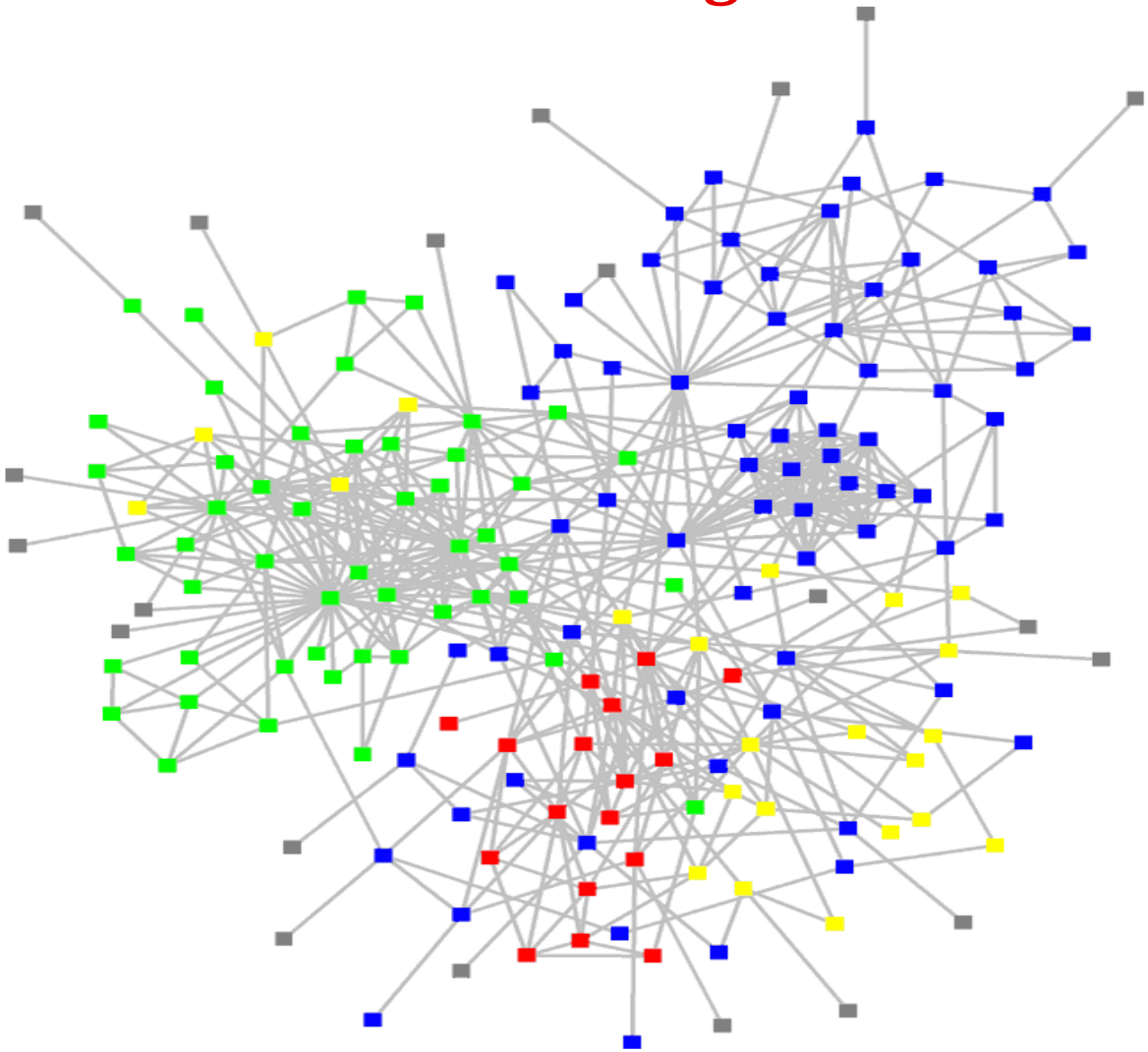
Internet







Structure of an organization



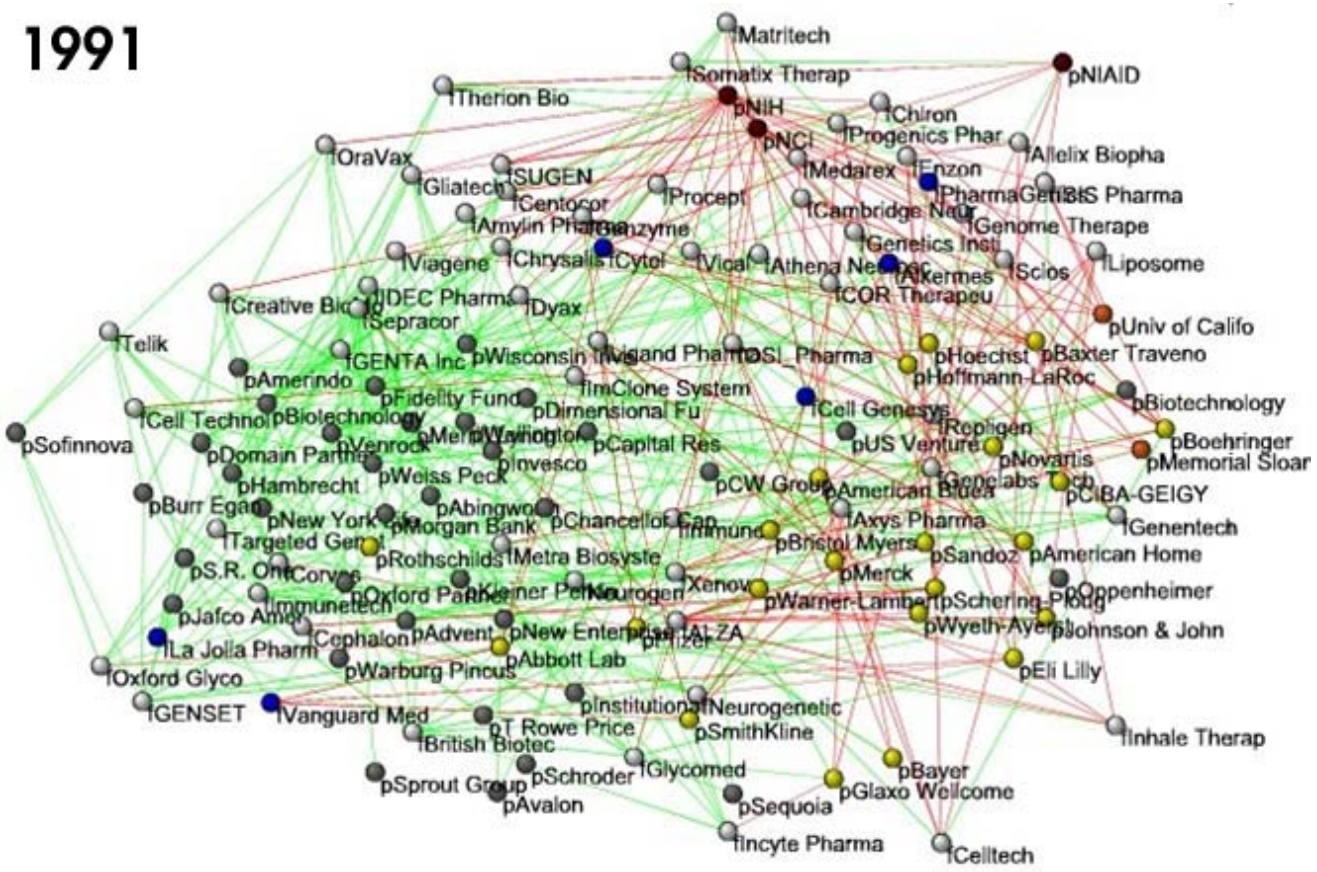
Red, blue, or green: departments

Yellow: consultants

Grey: external experts

www.orgnet.com

Business ties in US biotech-industry



Nodes: companies

investment

pharma

research labs

public

biotechnology

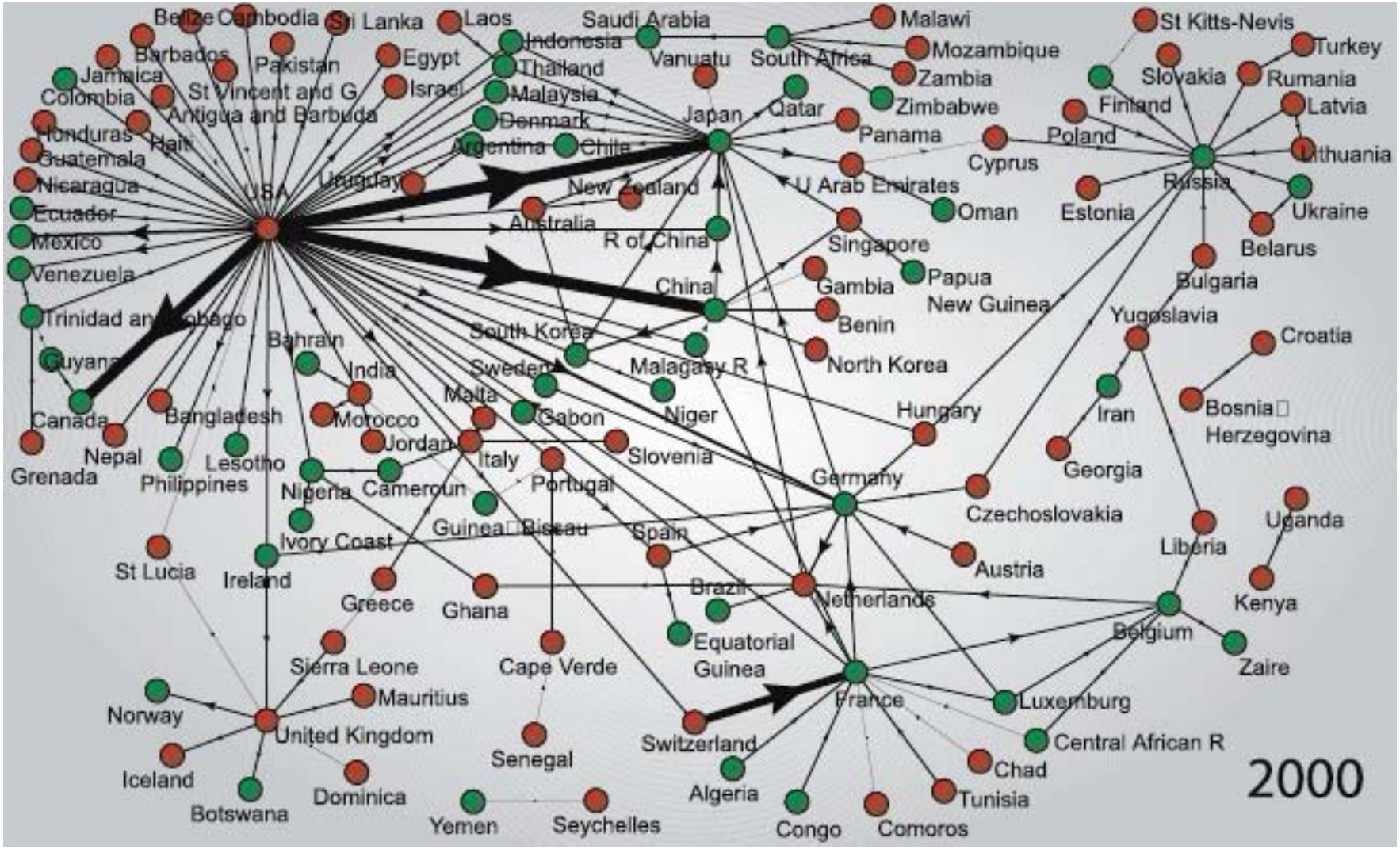
Links: collaborations

financial

R&D

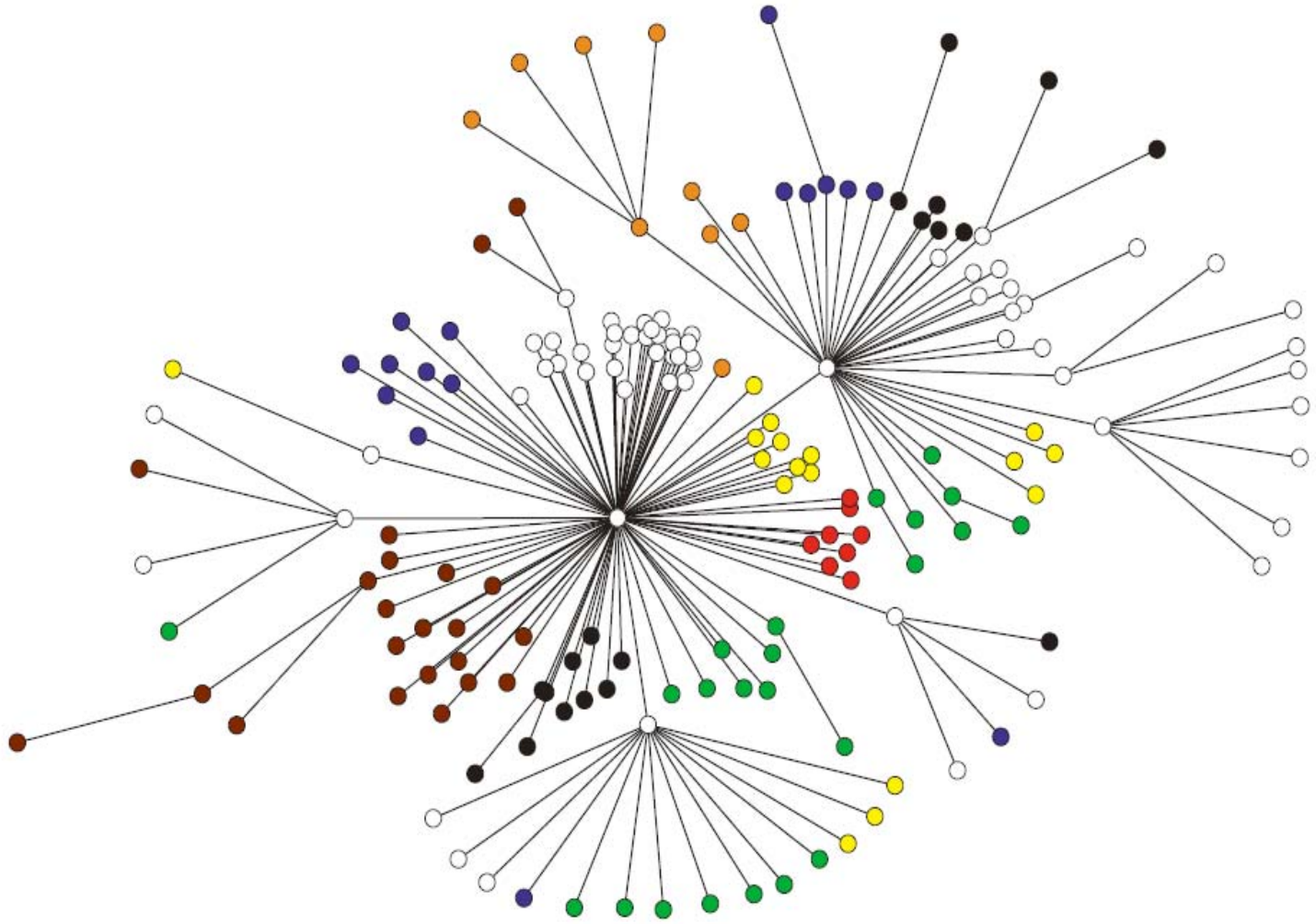
http://ecclectic.ss.uci.edu/~drwhite/Movie

Trade Imbalance Network



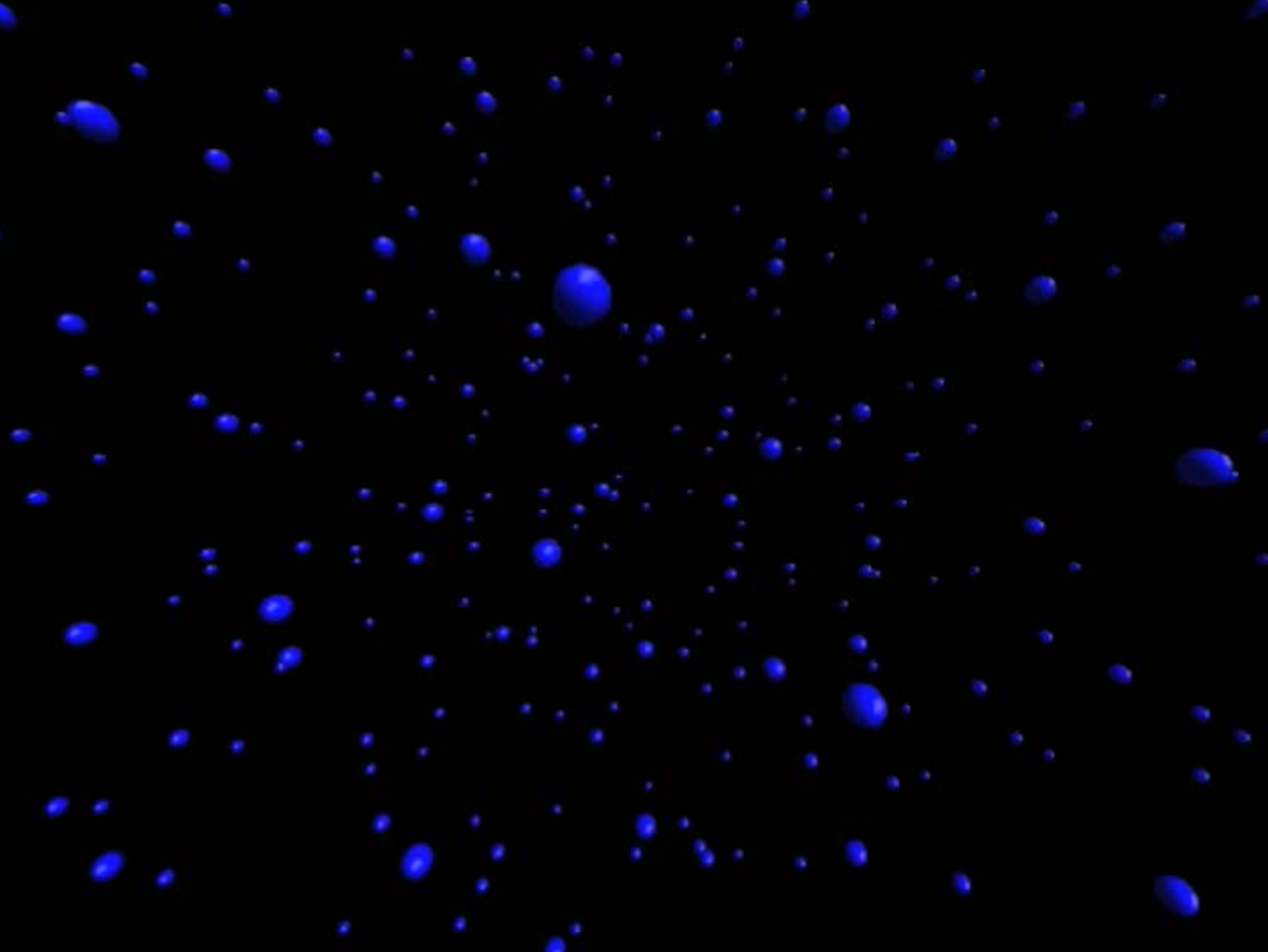
World trade imbalance web for 2000. Directed network of merchandise trade imbalances between world countries. Each country appears as a node and the direction of the arrow follows that of the net flow of money. (Serrano et al 2007).

Japanese Credit Network Between Banks



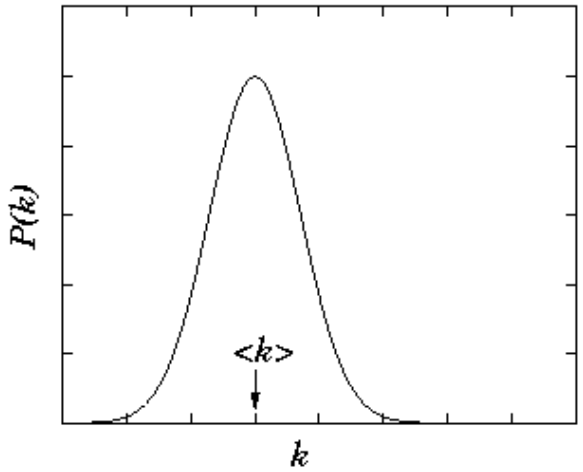
An Analysis of the Japanese Credit Network

G. De Masi, Y. Fujiwara, M. Gallegati, B. Greenwald, J. E. Stiglitz (16 Jan 2009)



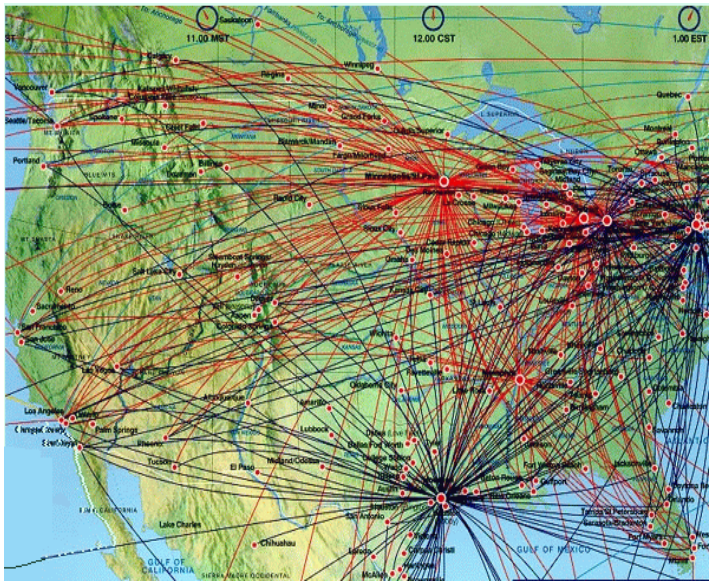
World Wide Web

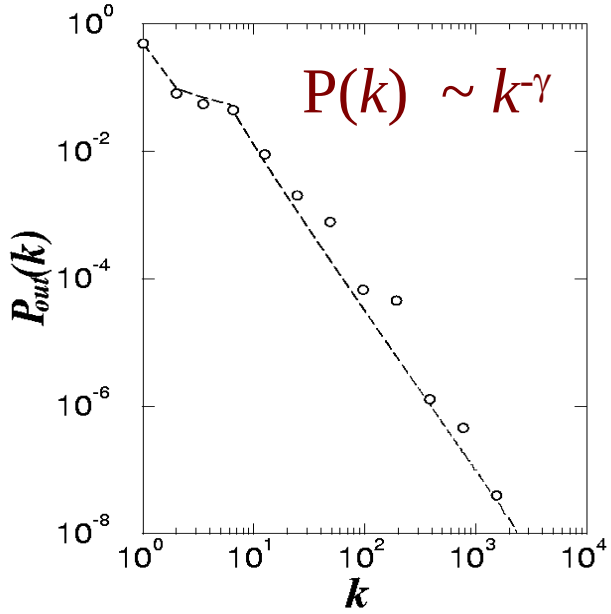
Exponential Network



Expected

Scale-free Network



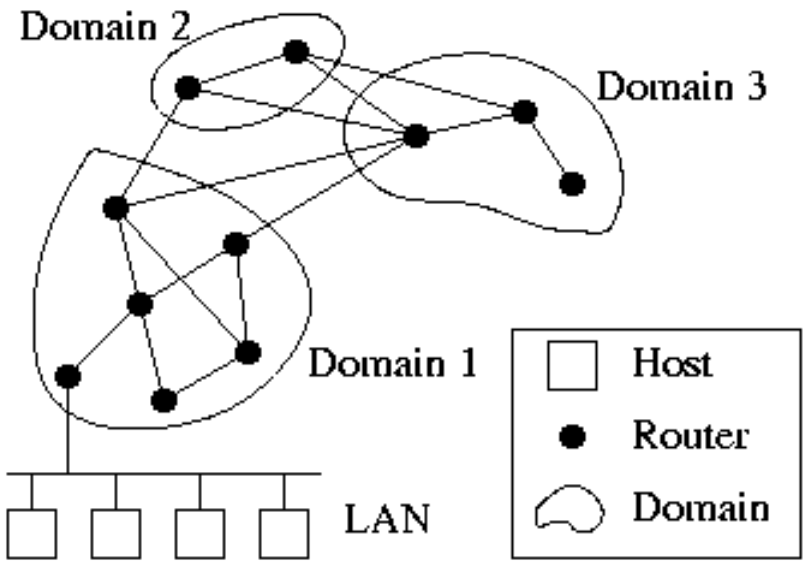


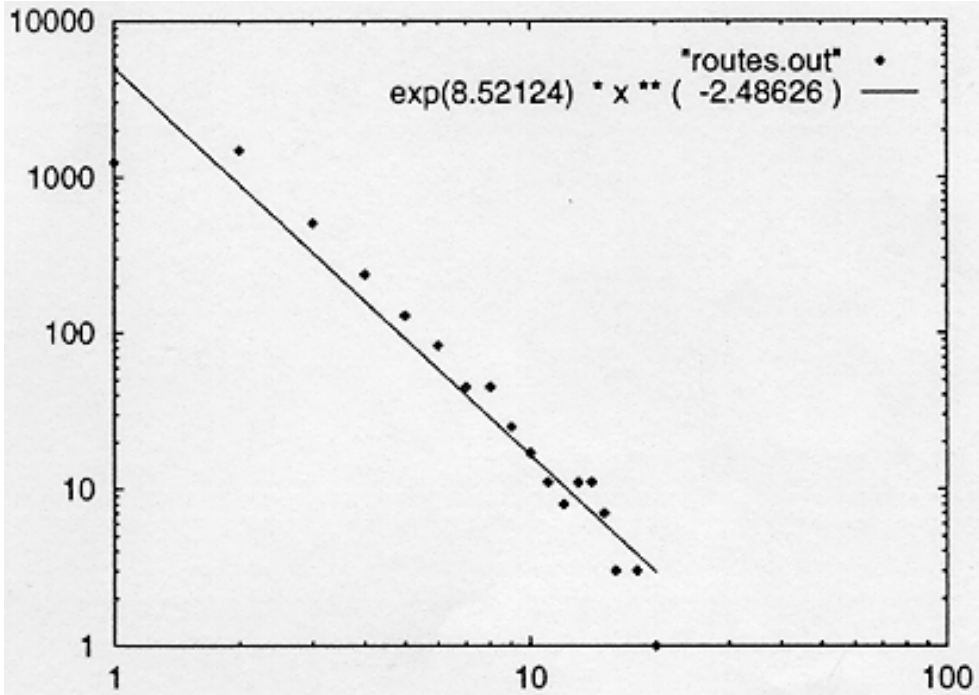
Found

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

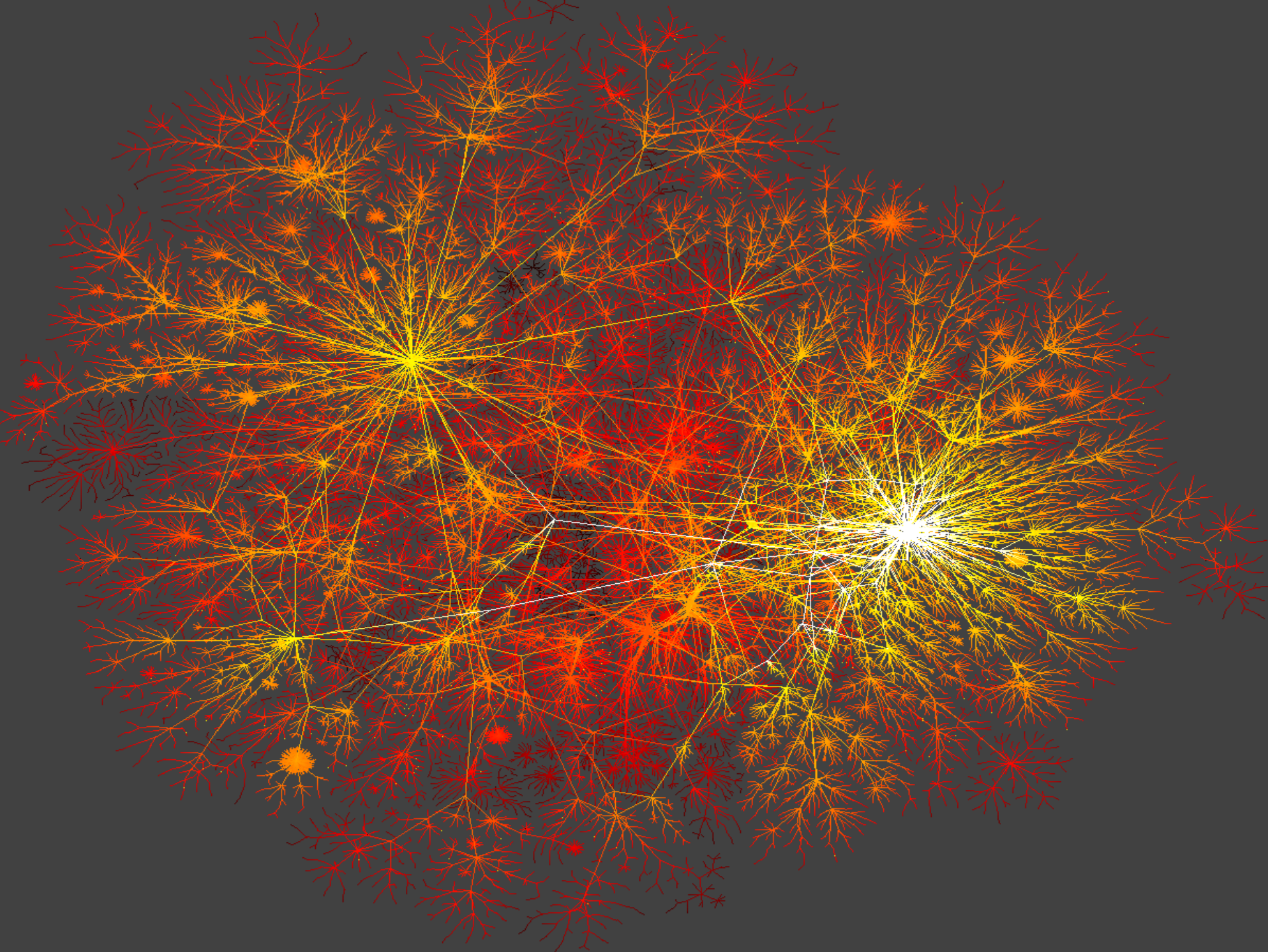
INTERNET BACKBONE

Nodes: computers, routers
Links: physical lines





(Faloutsos, Faloutsos and Faloutsos, 1999)



Origin of SF networks: Growth and preferential attachment

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

WWW : addition of new documents

GROWTH:

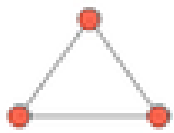
add a new node with m links

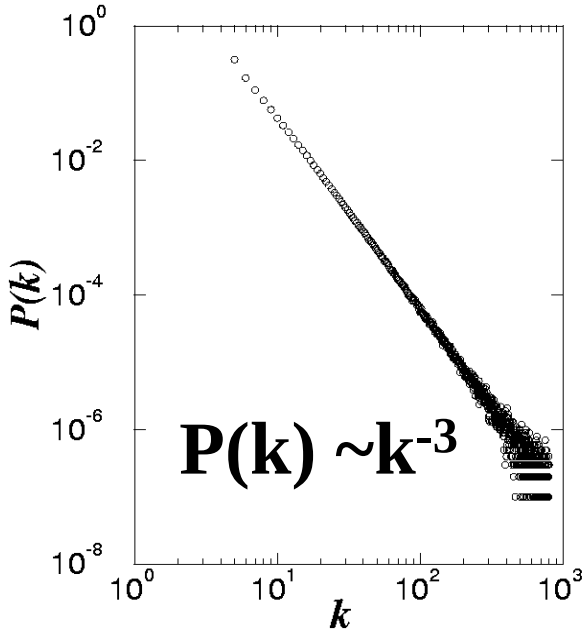
(2) New nodes prefer to link to highly connected nodes.

WWW : linking to well known sites

PREFERENTIAL ATTACHMENT: the probability that a node connects to a node with k links is proportional to k.

$$\Pi(k_i) = \frac{k_i}{\sum_i k_i}$$





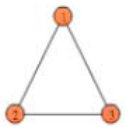
Barabási & Albert, *Science* **286,** 509 (1999)

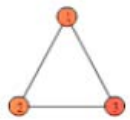
Fitness Model: Can Latecomers Make It?

SF model: $k(t) \sim t^{1/2}$ **(first mover advantage)**

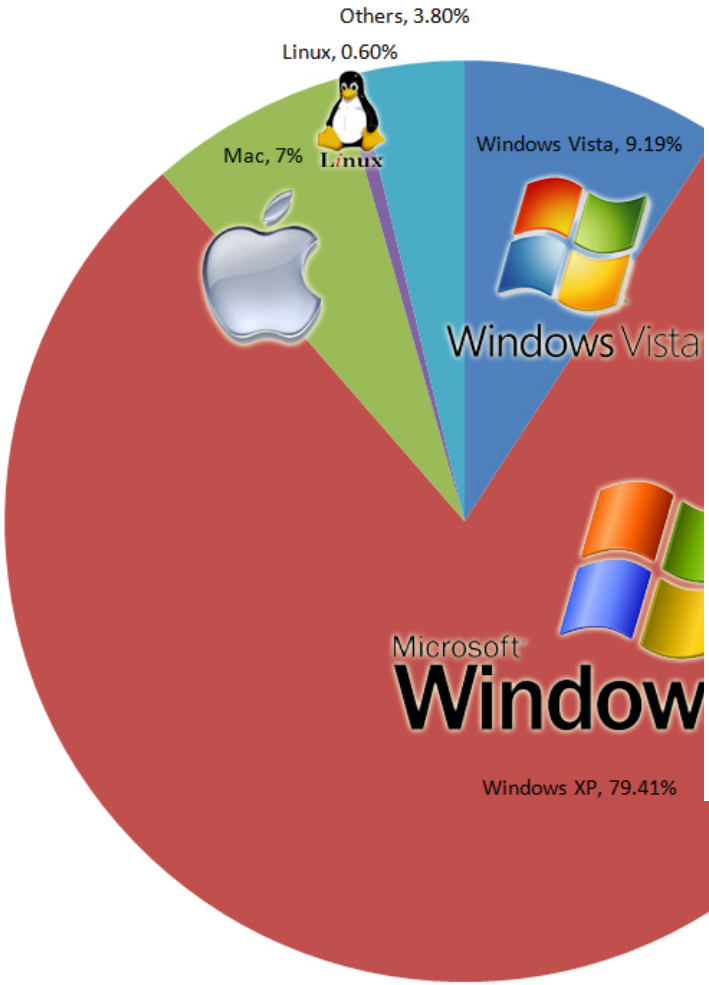
Fitness model: **fitness** (η) $\Pi(k_i) \cong \frac{\eta_i k_i}{\sum_j \eta_j k_j}$ $k(\eta,t) \sim t^{\beta(\eta)}$

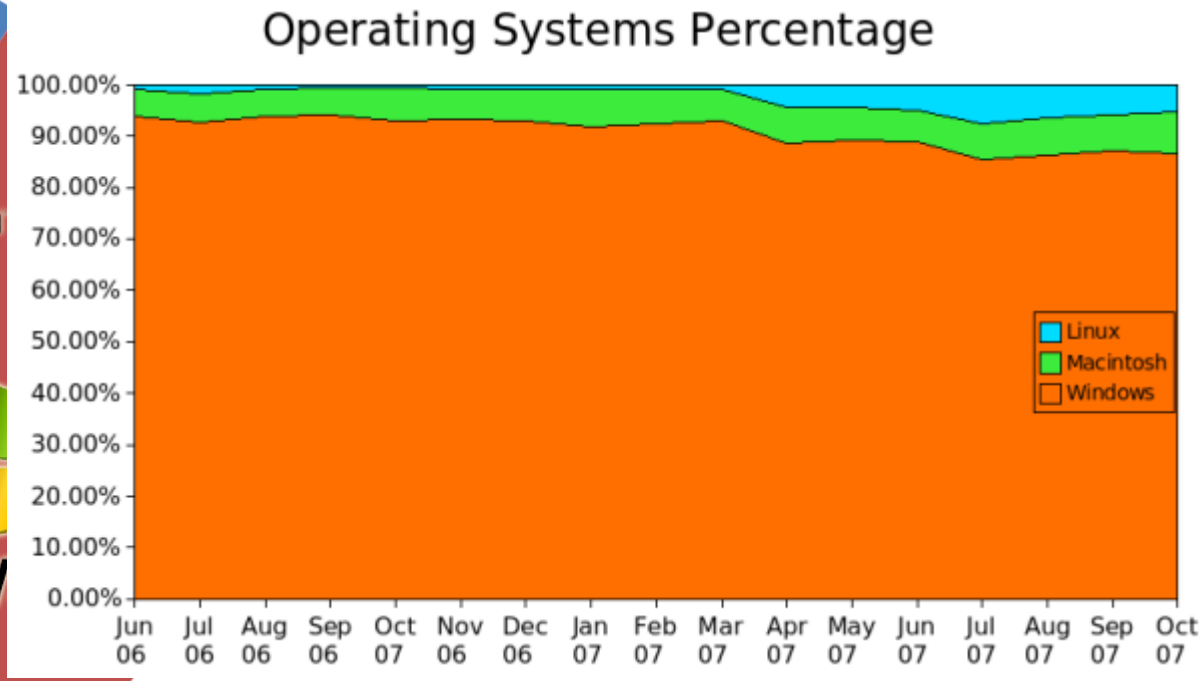
$\beta(\eta) = \eta / C$





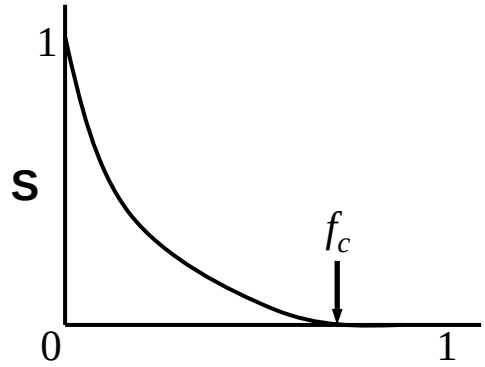
Bianconi & Barabási, *Physical Review Letters* 2001; *Europhys. Lett.* 2001.


Others, 3.80%
Linux, 0.60%
Mac, 7%
Windows Vista, 9.19%
Windows XP, 79.41%

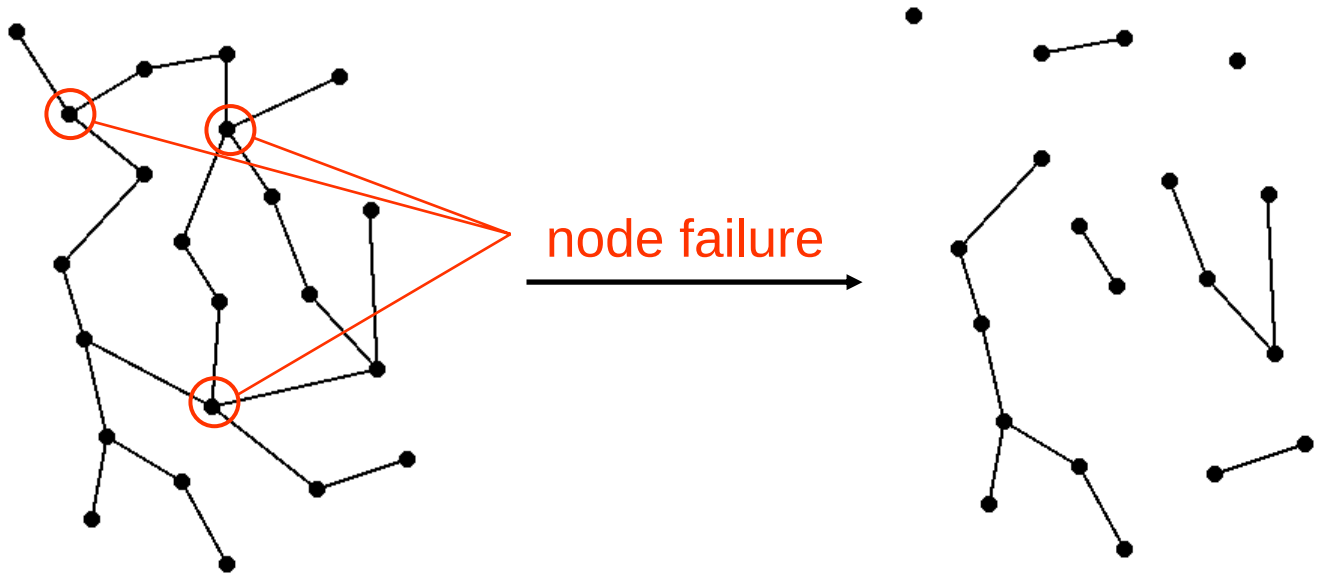

Operating Systems Percentage
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Jun 06
Jul 06
Aug 06
Sep 06
Oct 07
Nov 06
Dec 06
Jan 07
Feb 07
Mar 07
Apr 07
May 07
Jun 07
Jul 07
Aug 07
Sep 07
Oct 07
Linux
Macintosh
Windows

Robustness

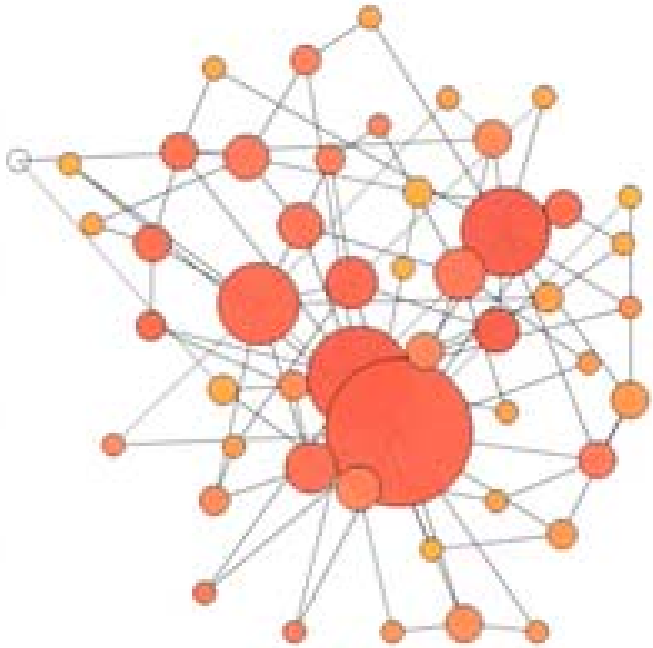
Complex systems maintain their basic functions even under errors and failures
(cell → mutations; Internet → router breakdowns)

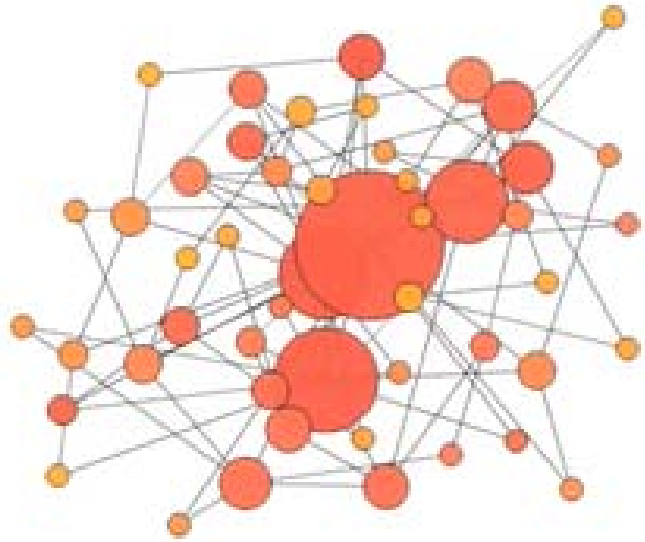


Fraction of removed nodes, *f*

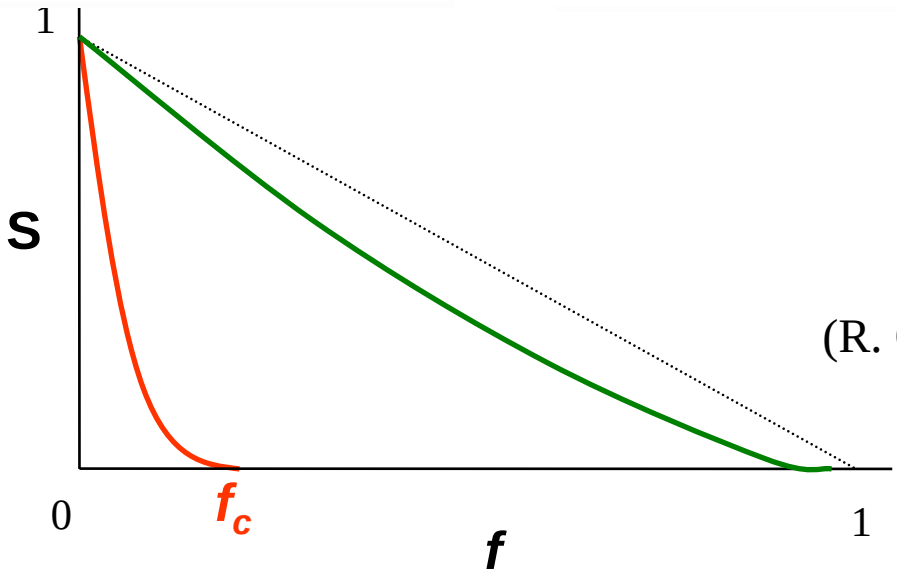


Robustness of scale-free networks





Attacks

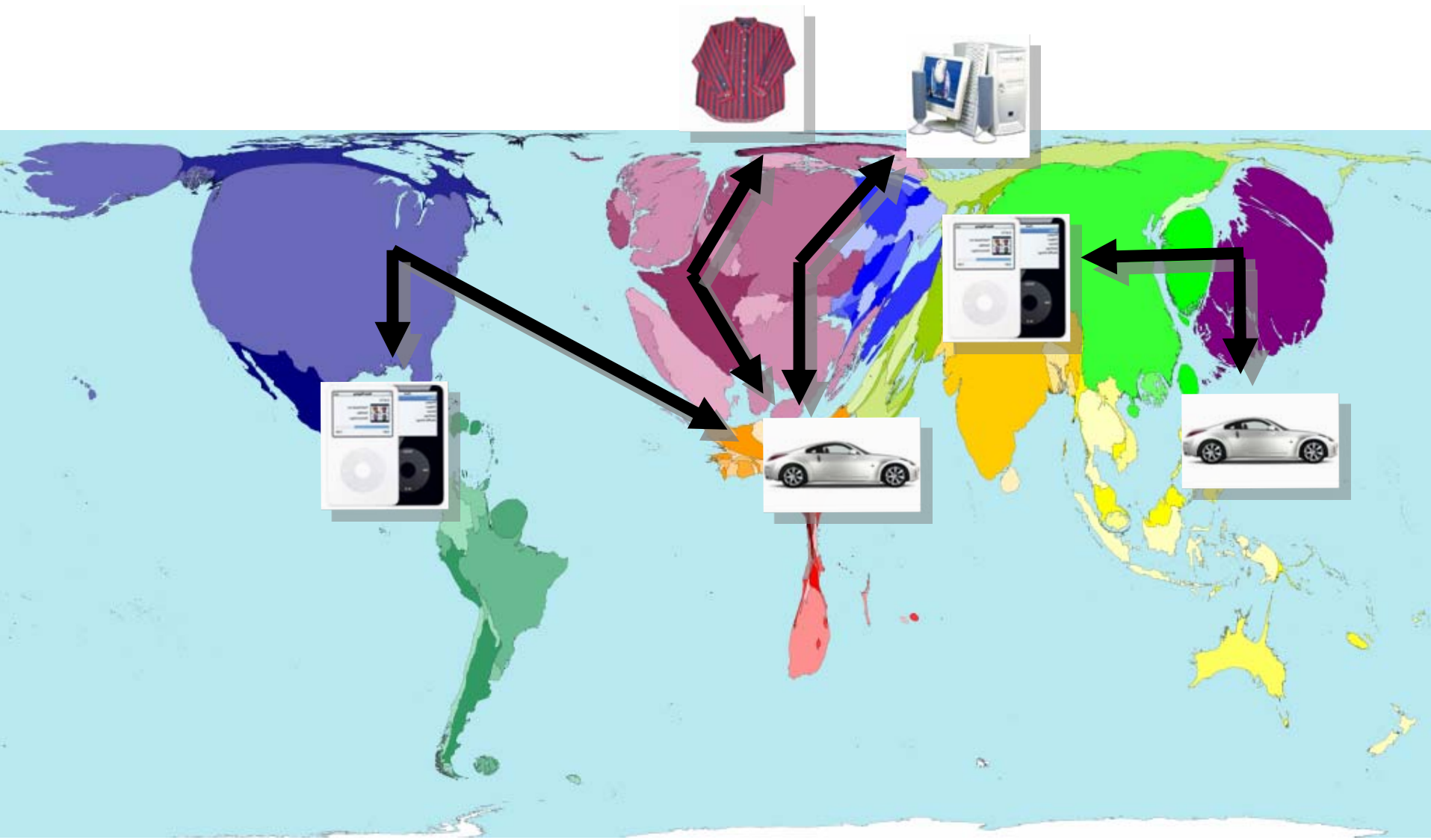


Failures

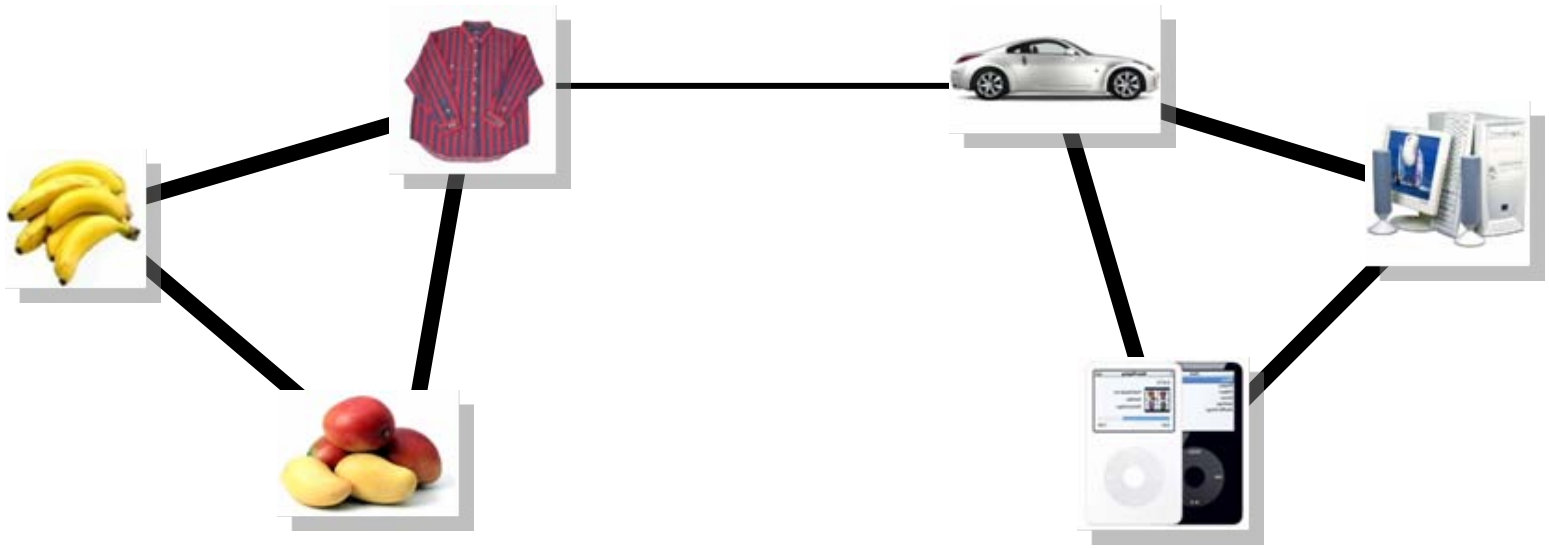
$\gamma \leq 3 : f_c=1$

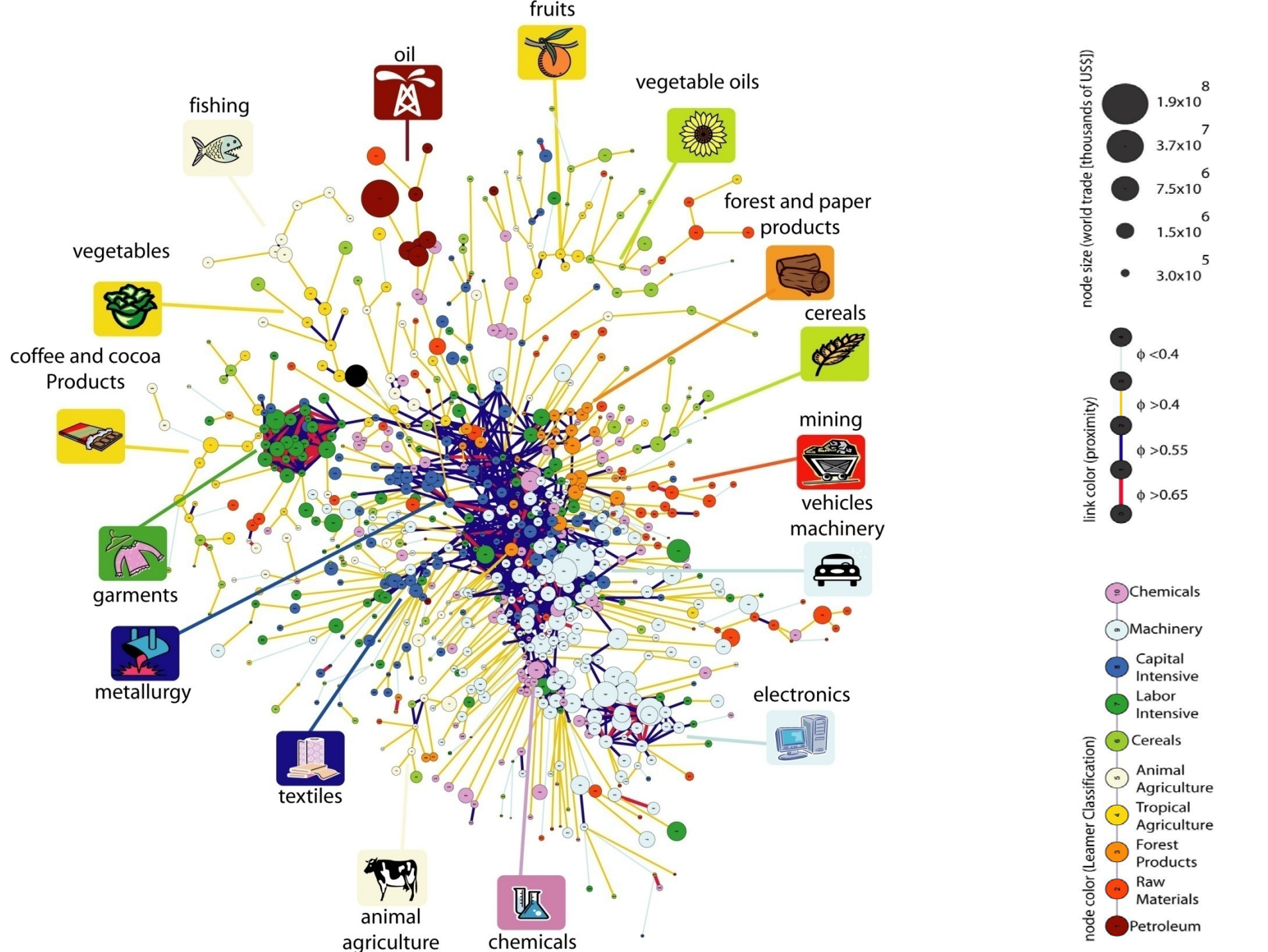
(R. Cohen et al PRL, 2000)

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



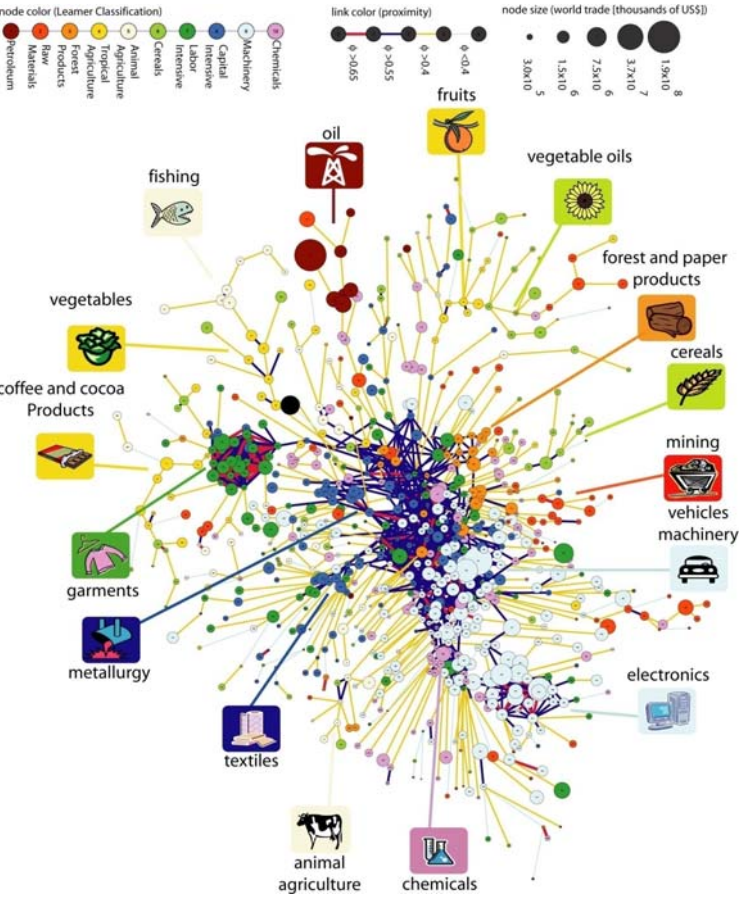
B. Balassa, *The Review of Economics and Statistics* 68, 315 (1986).



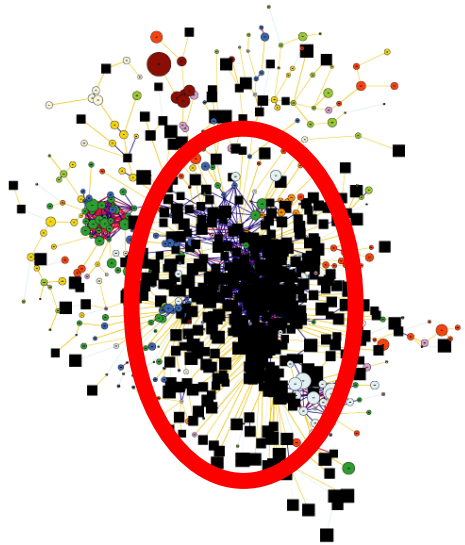

fruits
oil
vegetable oils
fishing
forest and paper products
vegetables
cereals
coffee and cocoa Products
mining
vehicles
machinery
garments
metallurgy
electronics
textiles
animal agriculture
chemicals
node size (world trade [thousands of US$])
1.9x10^8
3.7x10^7
7.5x10^6
1.5x10^6
3.0x10^5
link color (proximity)
ϕ <0.4
ϕ >0.4
ϕ >0.55
ϕ >0.65
node color (Leamer Classification)
Chemicals
Machinery
Capital Intensive
Labor Intensive
Cereals
Animal Agriculture
Tropical Agriculture
Forest Products
Raw Materials
Petroleum

KEY

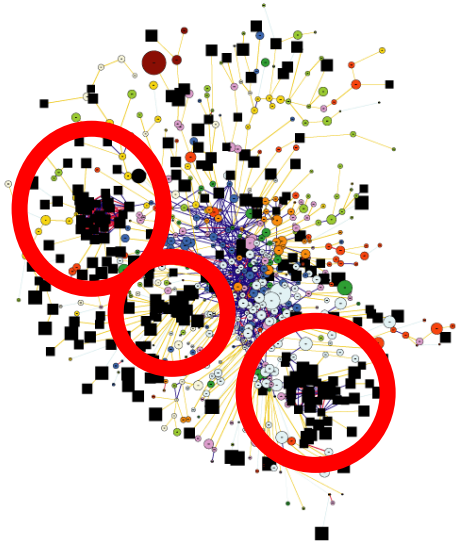
Denotes where region has RCA



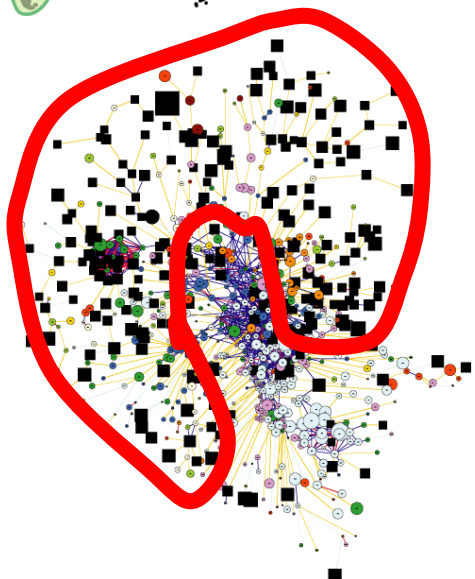
Industrialized Countries



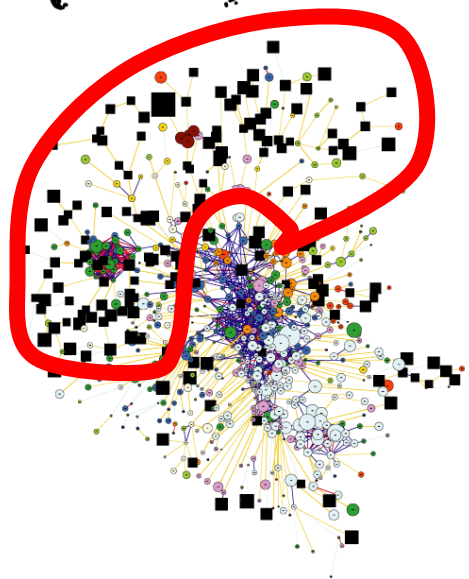
East Asia Pacific



Latin America and the Caribbean

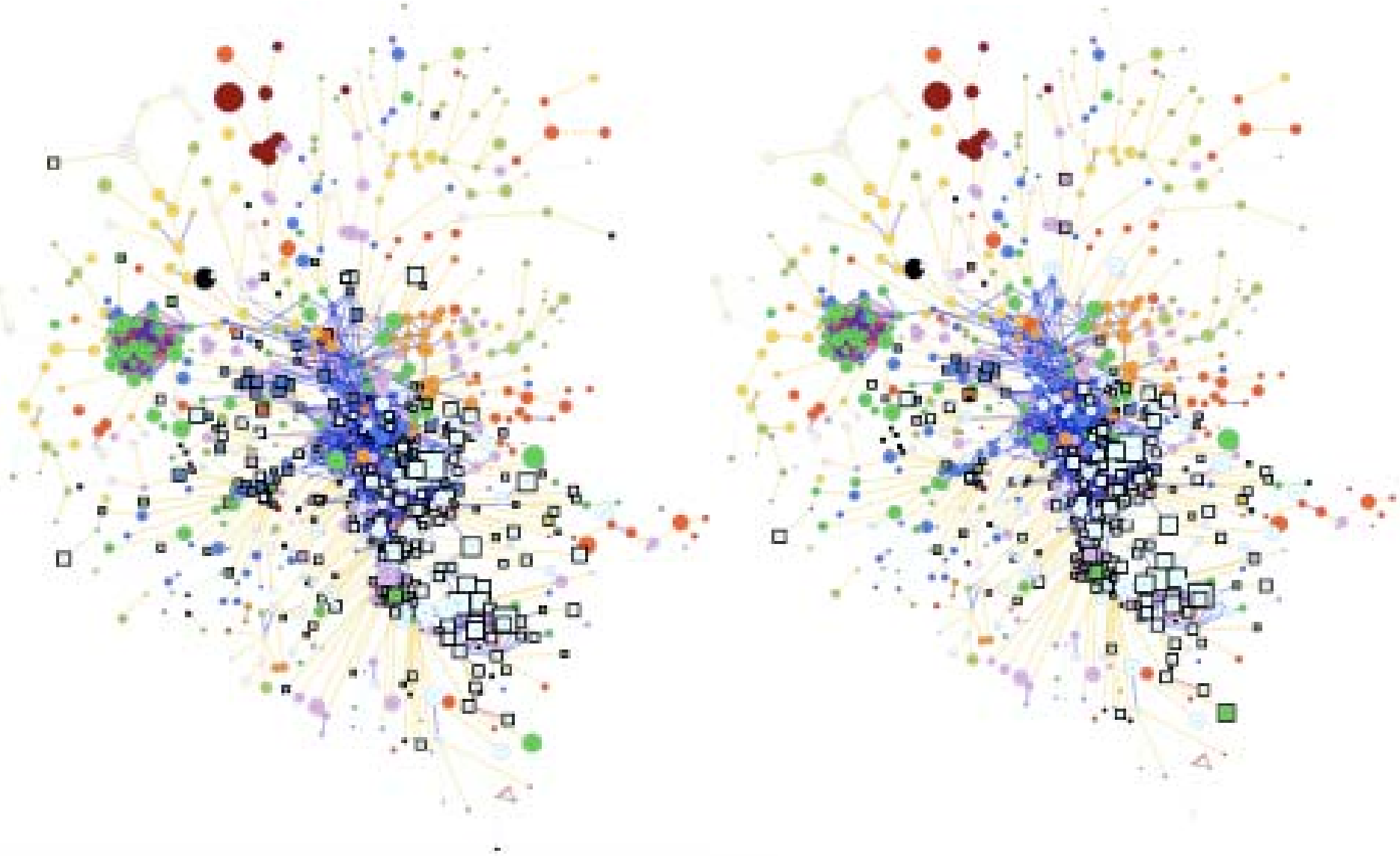


Sub-Saharan Africa



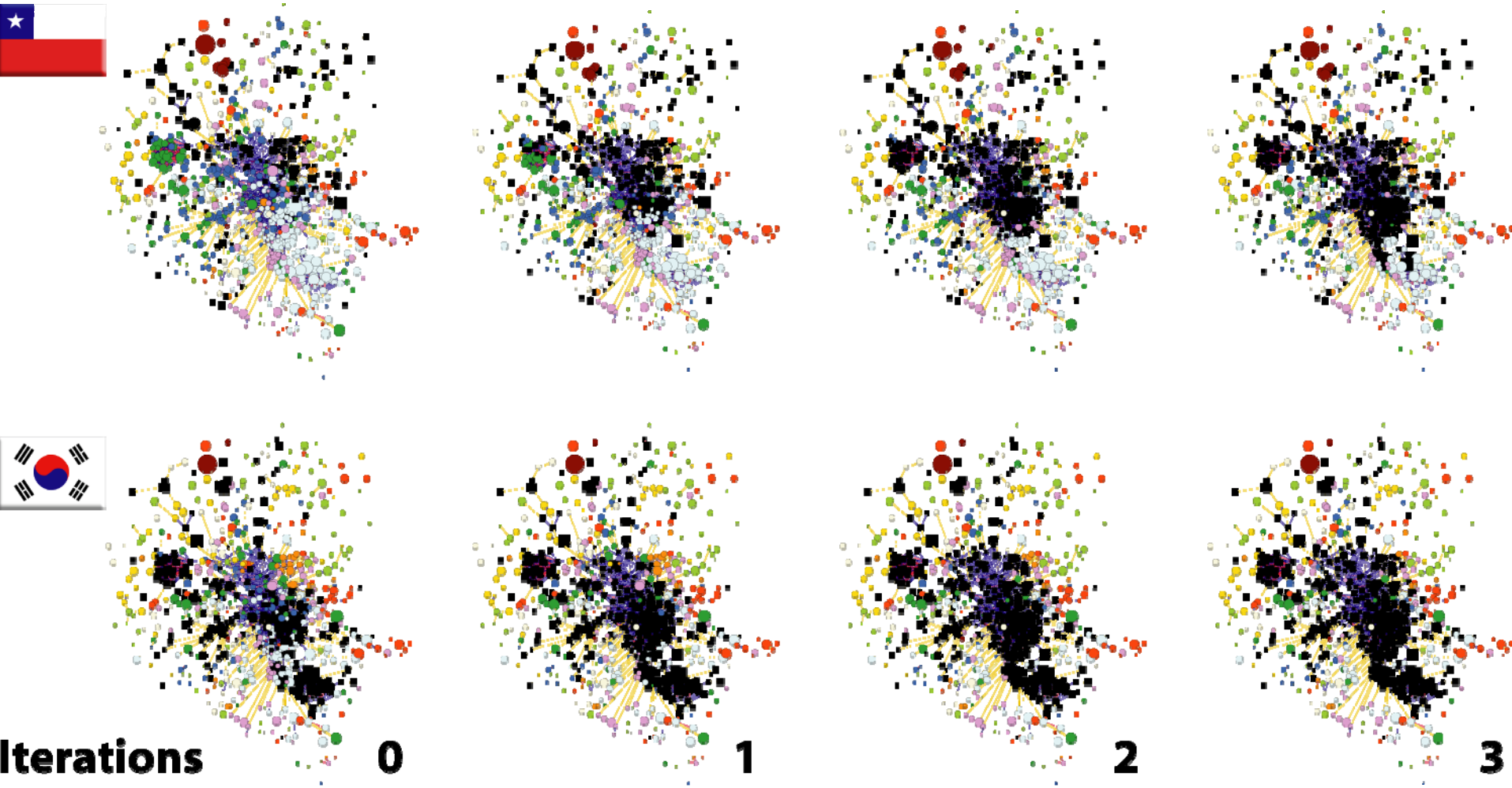
Japan 1985

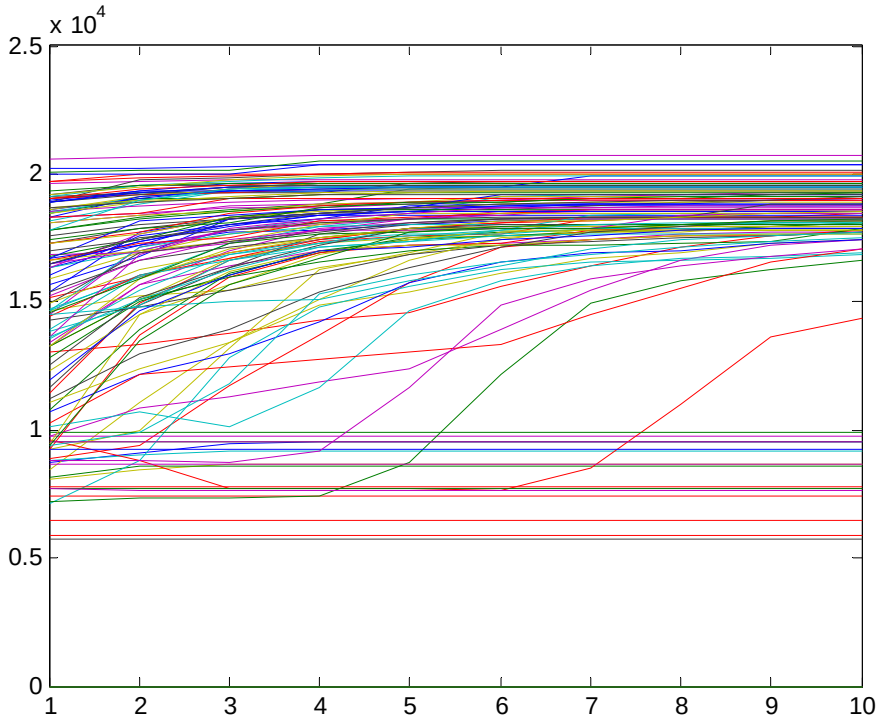
Japan 2000



http://www.nd.edu/~networks/productspace/index.htm

Iterated Diffusion (ϕ=0.55)

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2
1.5
1
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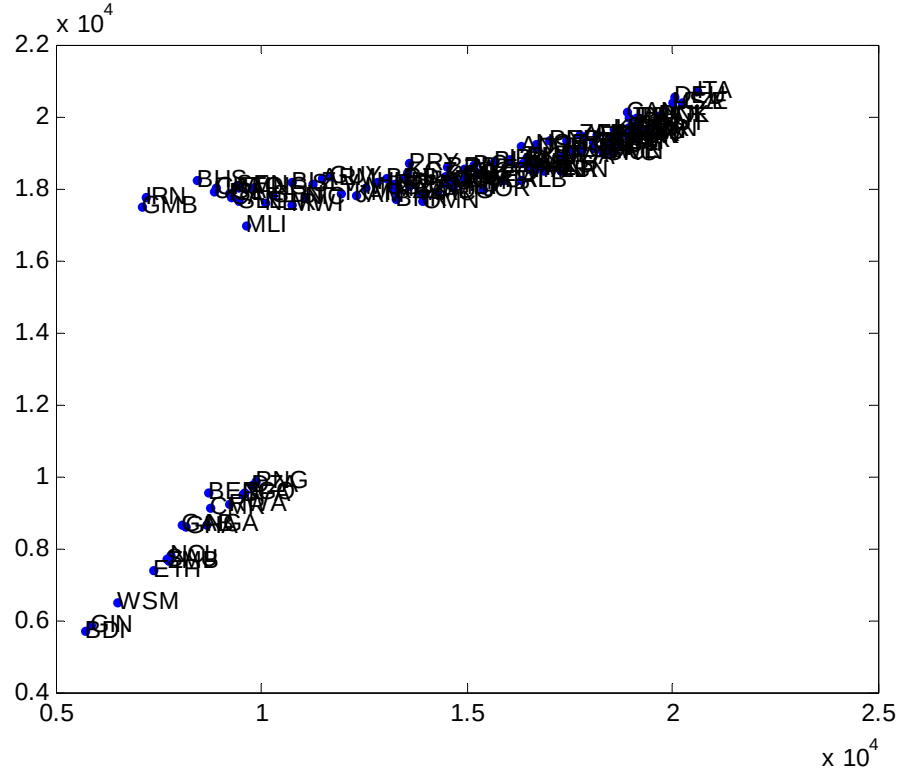
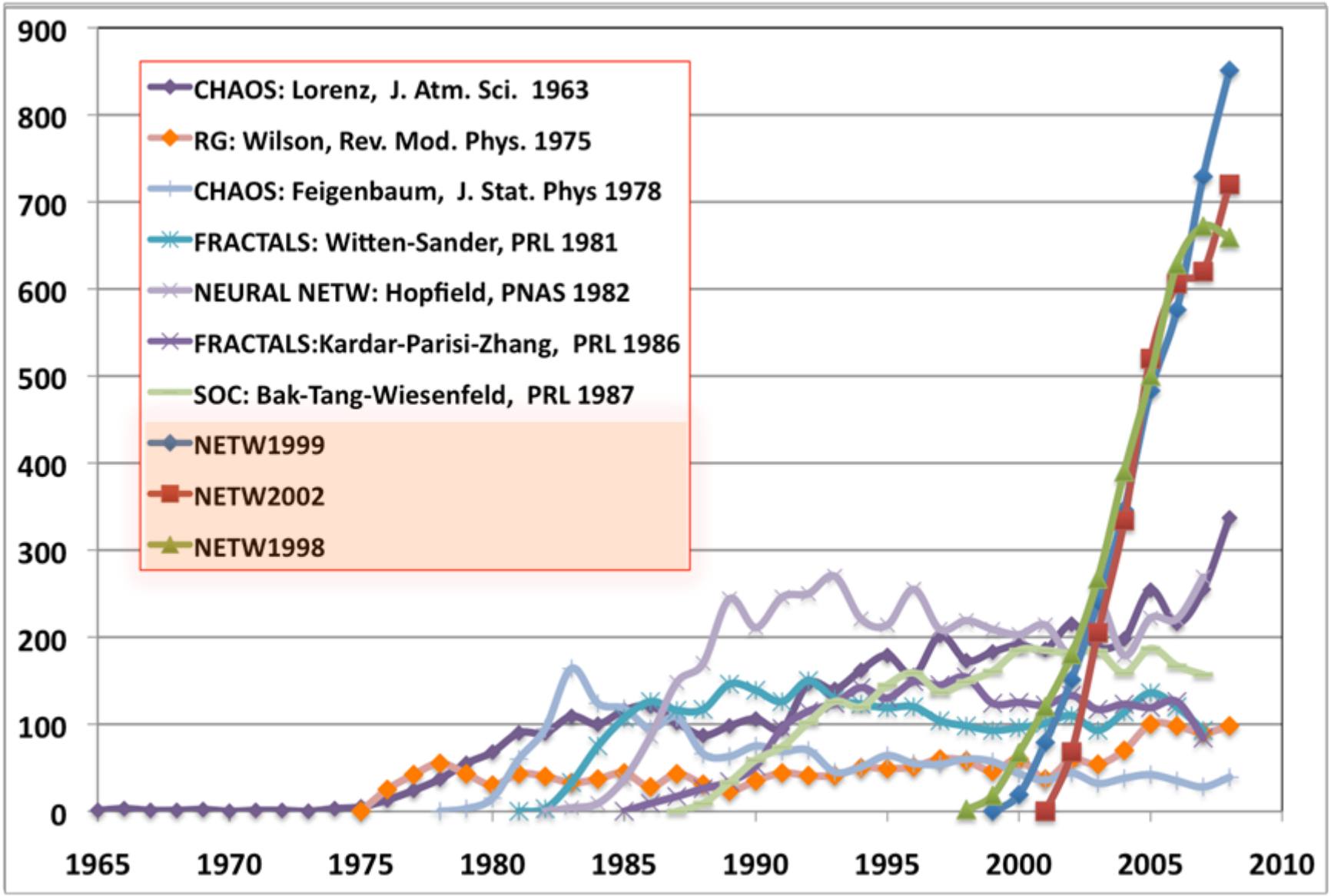
0
1
2
3
4
5
6
7
8
9
10


x 10^4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.5
1
1.5
2
2.5
x 10^4
IRN
GMB
MLI
WSM


900
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1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
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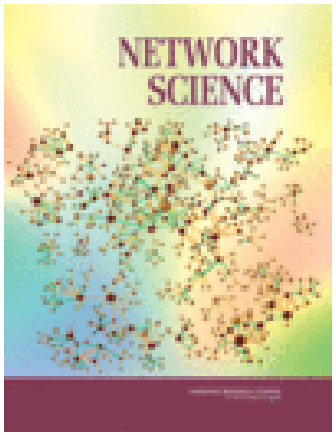
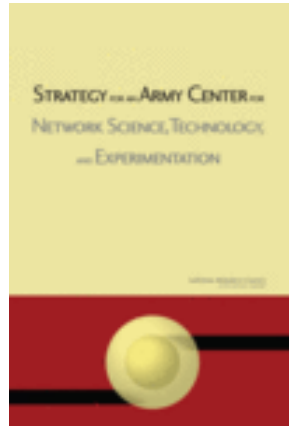
RG: Wilson, Rev. Mod. Phys. 1975
CHAOS: Feigenbaum, J. Stat. Phys 1978
FRACTALS: Witten-Sander, PRL 1981
NEURAL NETW: Hopfield, PNAS 1982
FRACTALS:Kardar-Parisi-Zhang, PRL 1986
SOC: Bak-Tang-Wiesenfeld, PRL 1987
NETW1999
NETW2002
NETW1998

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

NRC Panel on “Network Science”





What is “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.*

Réka Albert,	Penn State
Hawoong Jeong,	KAIST, Korea
Ginestra Bianconi,	ICTP, Trieste
Kwang-Il Goh,	Korea University
Cesar Hidalgo,	Notre Dame
Mark Vidal,	Dana-Farber, Harvard
Michael E. Cusick,	Dana Farber, Harvard
David Valle,	Johns Hopkins
Barton Childs,	Johns Hopkins
Nicholas Christakis,	Harvard
Deok-Sun Lee,	Northeastern University & DF
Juyong Park,	Northeastern University & DF
Zoltan N. Oltvai,	Pitssburgh Medical School
Dashun Wang,	Northeastern University

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