EMERGENCE OF COMPLEXITY IN BIOLOGICAL NETWORKS

from selection to tinkering

ECCS, Jerusalem, September 2008

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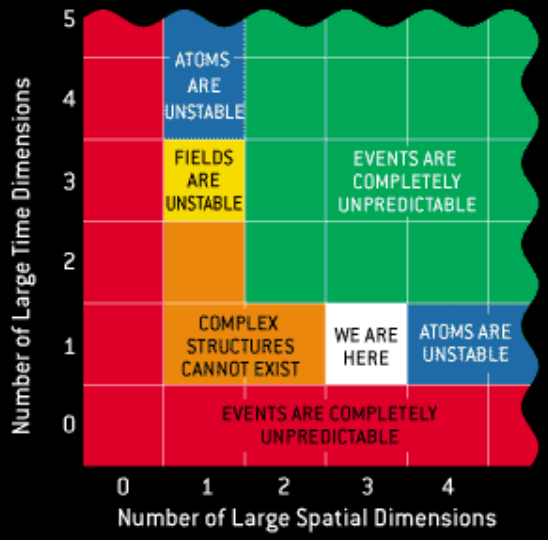
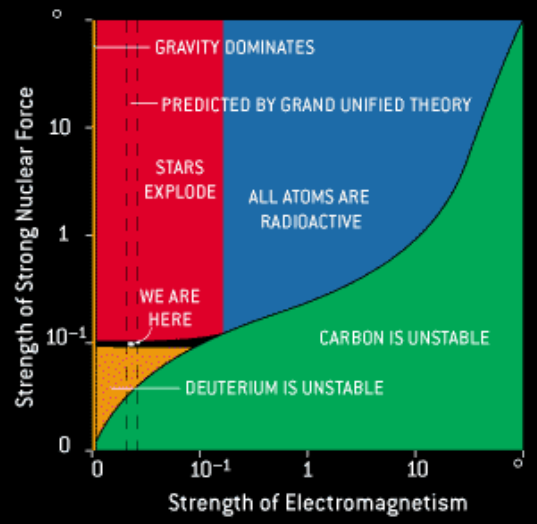
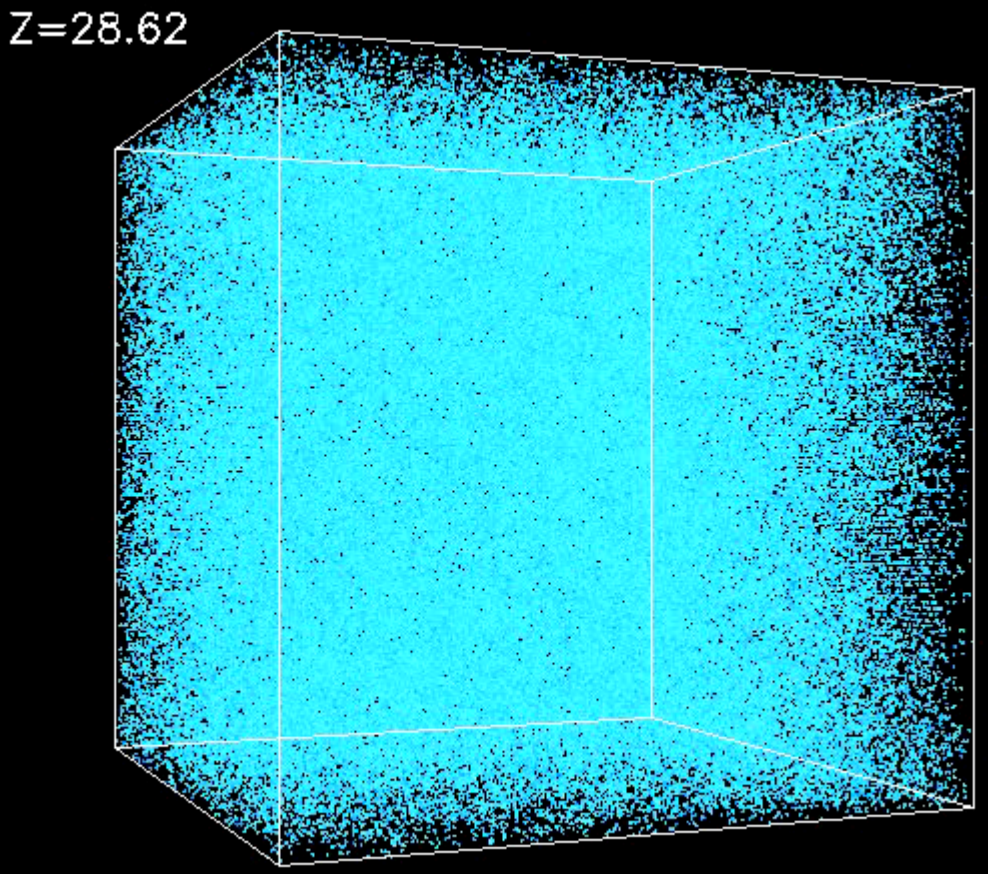
Evolution in physics?



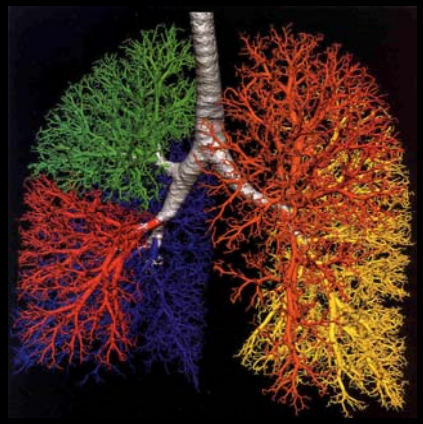




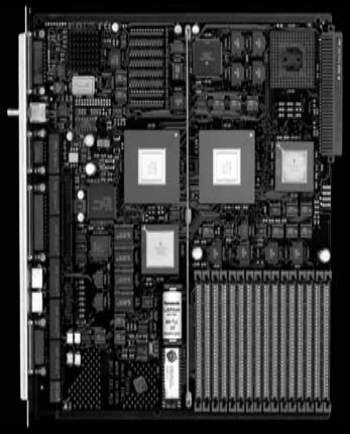
The Life of the Cosmos
Lee Smolin,Oxford U. Press (1997)

Evolution: how does it take place?

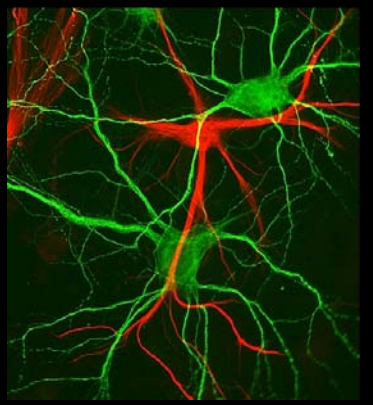
SELECTION

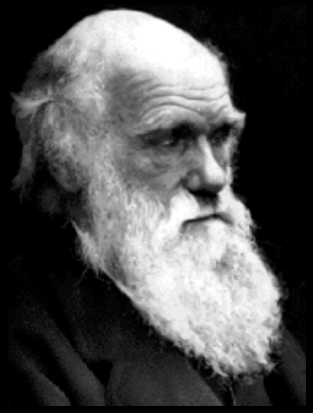


TINKERING



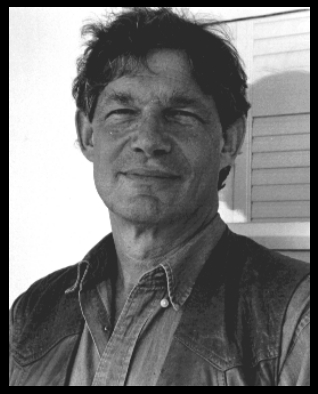
EMERGENCE





C. Darwin
“The Origin of Species”
(1859)

F. Jacob
“Evolution and Tinkering”
Science (1977)



S.Kauffman
“Origins of Order”
(1993)

Does evolution occur at all?

EVOLUTION IS A STUPID IDEA

THE BIG BANG IS A STUPID THEORY

TO BELIEVE IN LIFE ORIGINATED
FROM CHEMISTRY IS A STUPID IDEA

DON’T SUPPORT EVOLUTION IN SCHOOLS
PAYED WITH MY TAXES

Kent Hovind (creation “scientist”)

Can life be created in the lab?

I WORK FOR GOD, SO I DON'T HAVE TO PAY TAXES

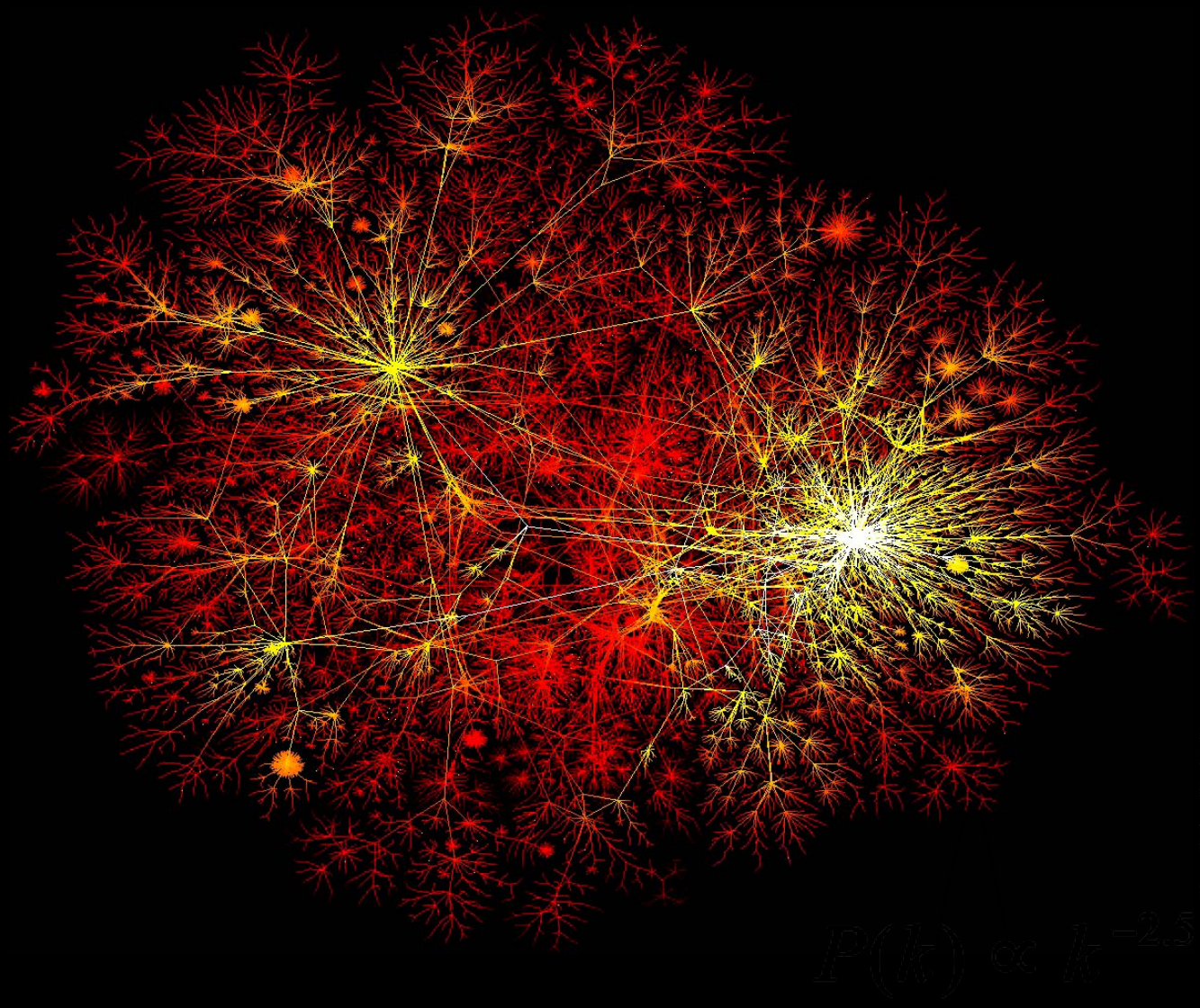
PAYING TAXES IS EVIL

Kent Hovind (creation "scientist")

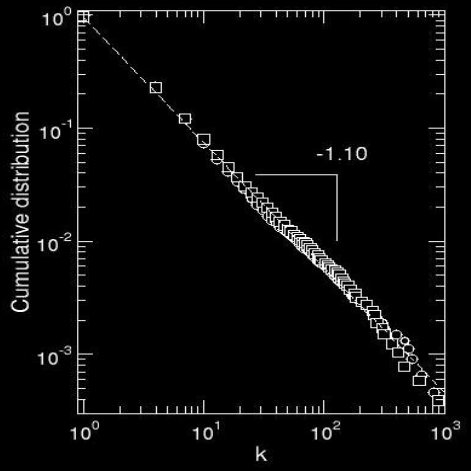
Evolution of complexity: networks

www.nrbsc.org/ brainmovie/index.html

Complex networks are scale-free



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

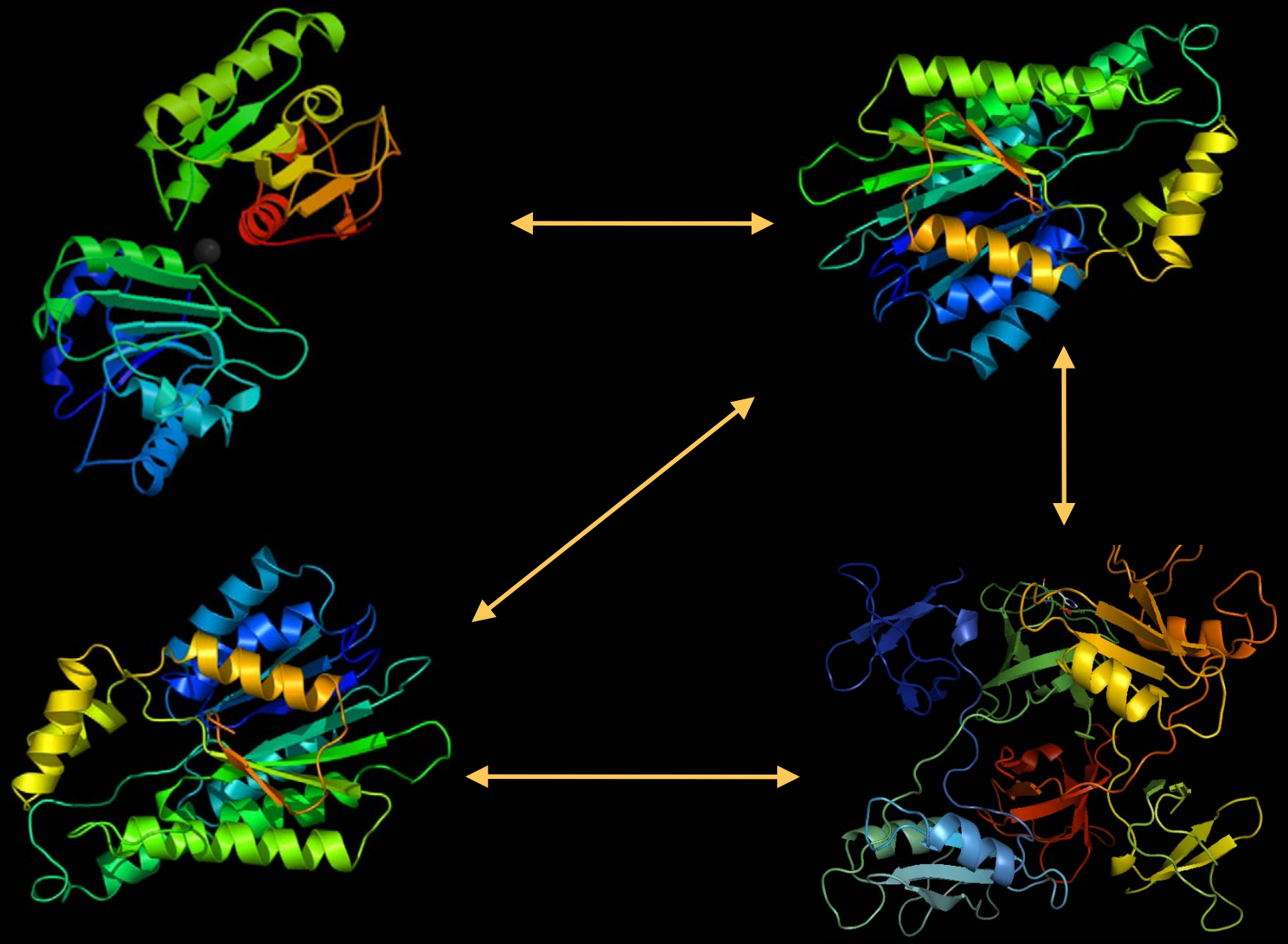


Cell Biology

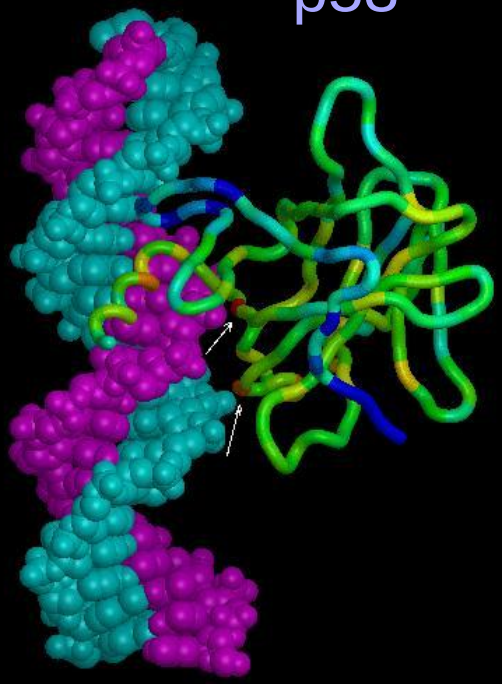
http://multimedia.mcb.harvard.edu

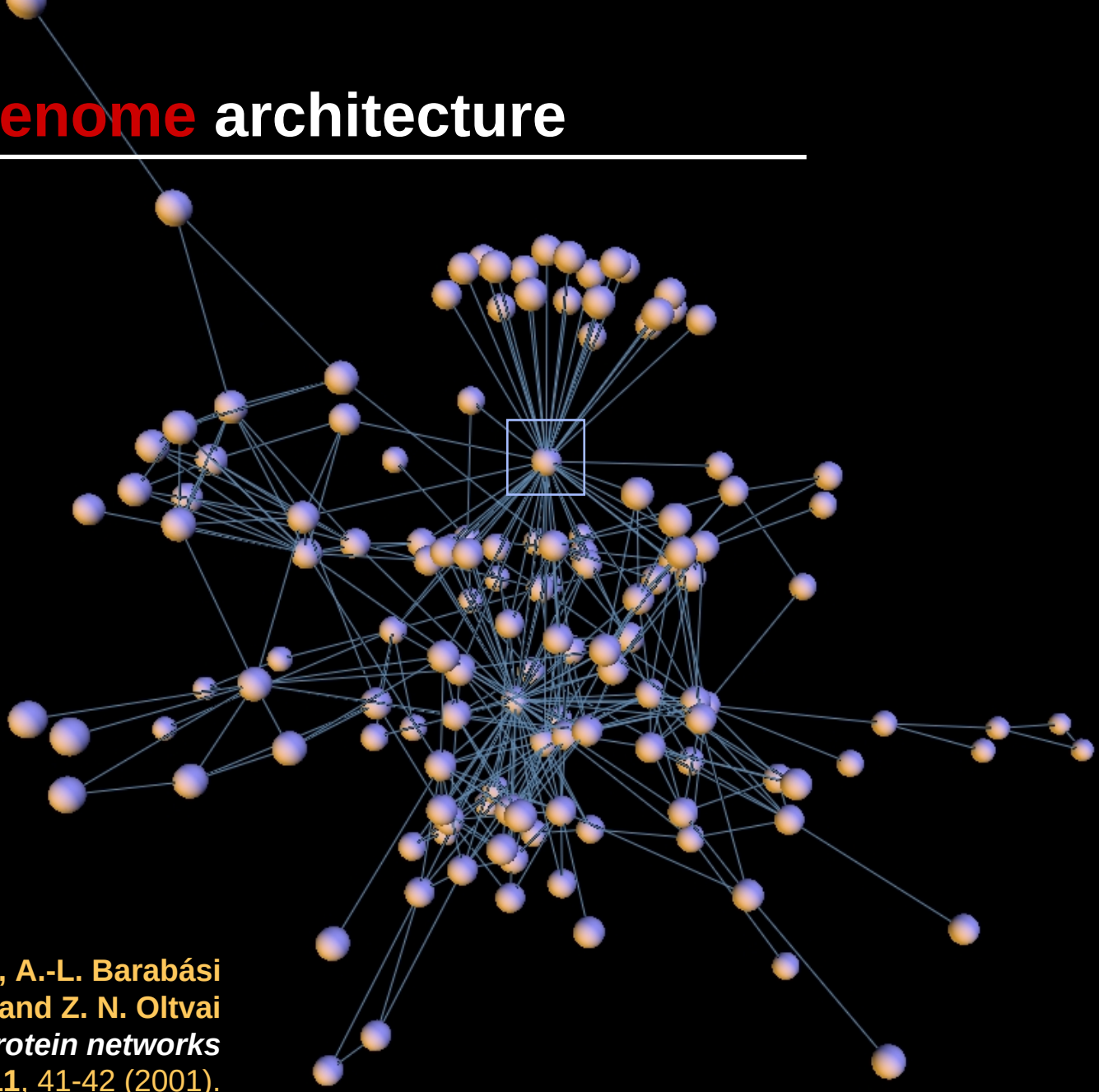
What is the architecture of cellular maps?
What are the consequences?
What are the origins?

The small world of protein interactions



Scale-free genome architecture





H. Jeong, S. Mason, A.-L. Barabási and Z. N. Oltvai
Lethality and centrality in protein networks
Nature **411**, 41-42 (2001).

Proteome: small world, scale free

Topology, tinkering and evolution of the human transcription factor network

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1 ICREA-Complex Systems Laboratory, Universitat Pompeu Fabra, Barcelona, Spain
2 Department of Molecular Biology and Biochemistry, Faculty of Sciences, Universidad de Málaga, Spain
3 Santa Fe Institute, Santa Fe, New Mexico, USA

FEBS Journal 272 (2005) 6423-6434

Table 2. Description and functionality of transcriptions factor hubs. Transcription factor (TF), degree (k), betweenness centrality (b).

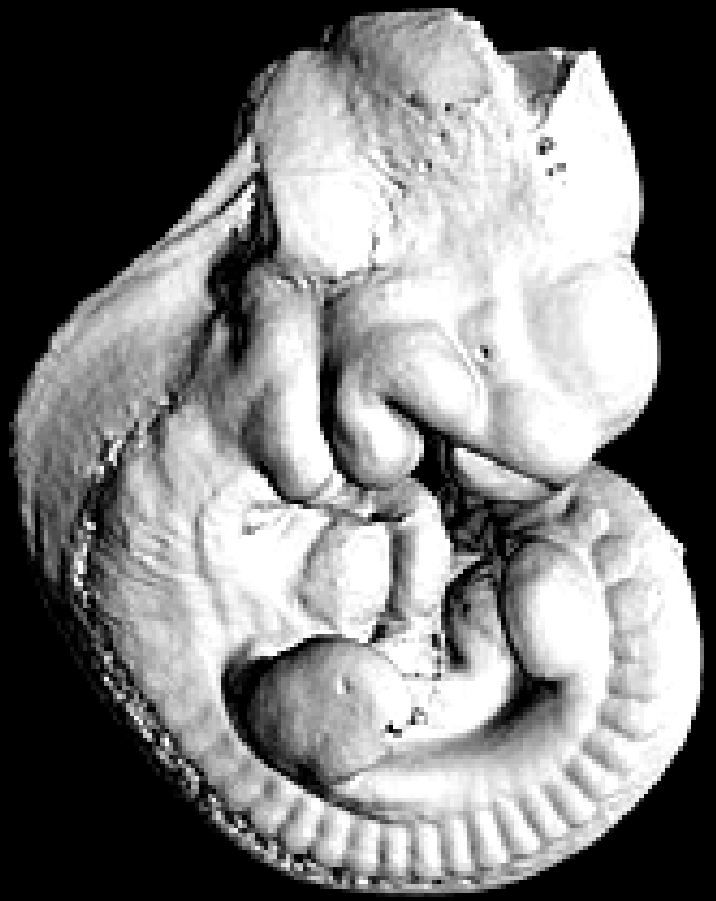
TF	Description	Associate disease	k	$b \times 10^3$
TBP	Basal transcription machinery initiator	Spinocerebellar ataxia [40]	27	17.3
p53	Tumor suppressor protein	Proliferative disease [68]	23	18.5
P300	Coactivator. Histone acetyltransferase	May play a role in epithelial cancer [69]	18	20.2
RXR-α	Retinoid X-α receptor	Hepatocellular carcinoma [70]	18	8
pRB	retinoblastoma suppressor protein. Tumour suppressor protein	Proliferative disease Bladder cancer. Osteosarcoma [71]	15	27.1
RelA	NF-κB pathway	Hepatocyte apoptosis and foetal death [72]	14	6.6
c-jun	AP-1 complex (activator). Proto-oncogen	Proliferative disease [73]	14	4.1
c-myc	Activator. Proto-oncogen	Proliferative disease [74]	13	10.5
c-fos	AP-1 complex (activator). Proto-oncogen	Proliferative disease [75]	12	2

Evolution of genome : how to model?

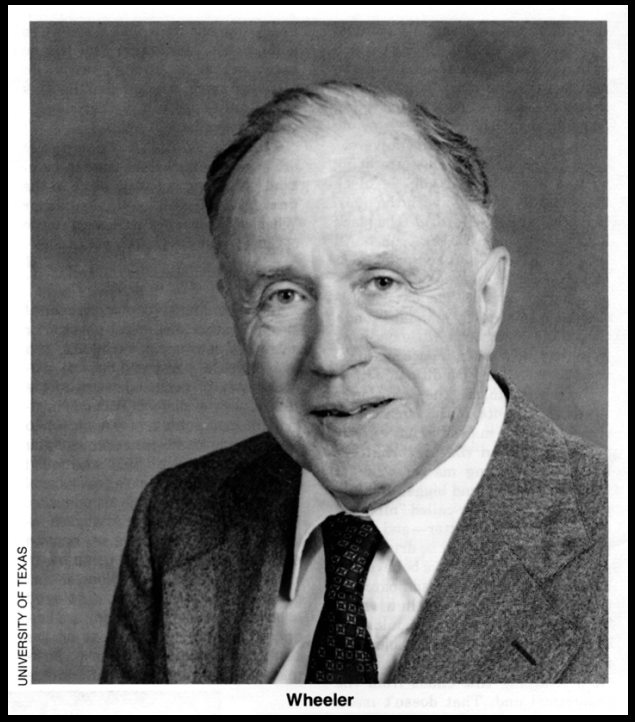
François Jacob (1976)

"Natural selection does not work as an engineer but as a tinkerer, limited by the constraints present at all levels of biological organization"

Science 196: 1161-1166



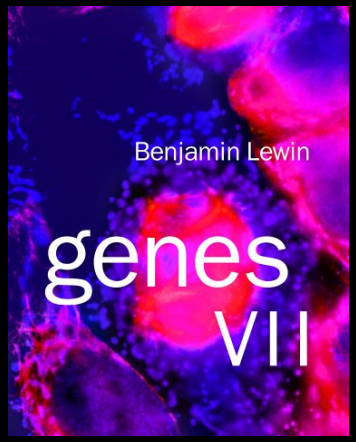
Complexity “for free”?

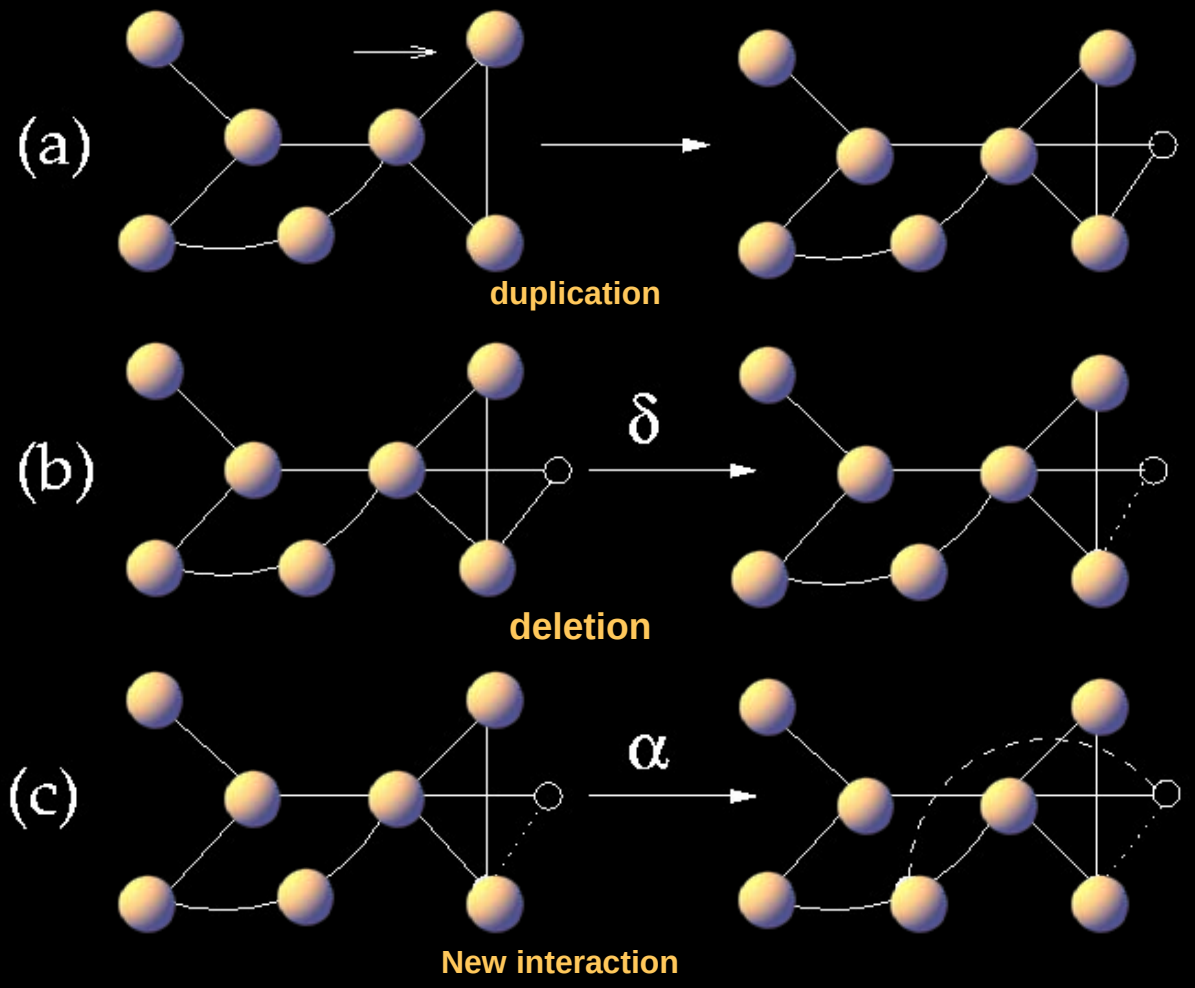


“If you haven’t found something strange during the day,
it hasn’t been much of a day”

John Wheeler

Origins of scale-free regulatory maps





Origins of scale-free regulatory maps

$$\frac{\mathrm{d}n_k(t)}{\mathrm{d}t} = \frac{n_k}{N} + \frac{\delta}{N}[(k+1)n_{k+1} - kn_k] + \frac{1-\delta}{N}[(k-1)n_{k-1} - kn_k] + \frac{2\beta}{N}[n_{k-1} - n_k].$$

$$p_k \sim (k_0 + k)^{-\gamma} \mathrm{e}^{-k/k_c}$$

with

$$\gamma = -k_0 = 1 - \frac{2\beta}{1-\delta}, \quad k_c = \frac{1}{\ln\left(\frac{\delta}{\delta-1}\right)}$$

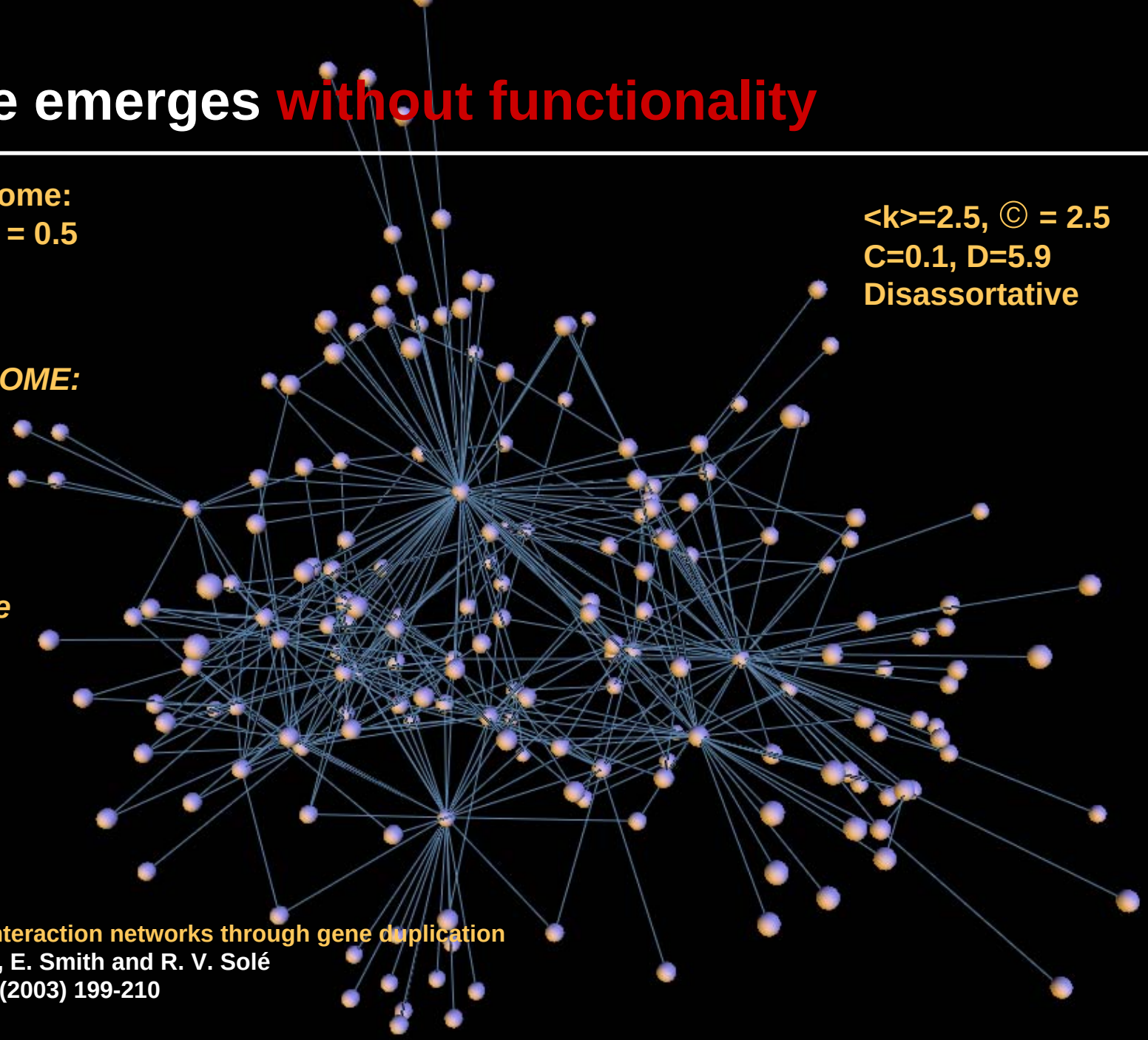
Structure emerges without functionality

Model proteome:
assuming ™ = 0.5

<k>=2.5, © = 2.5
C=0.1, D=5.9
Disassortative

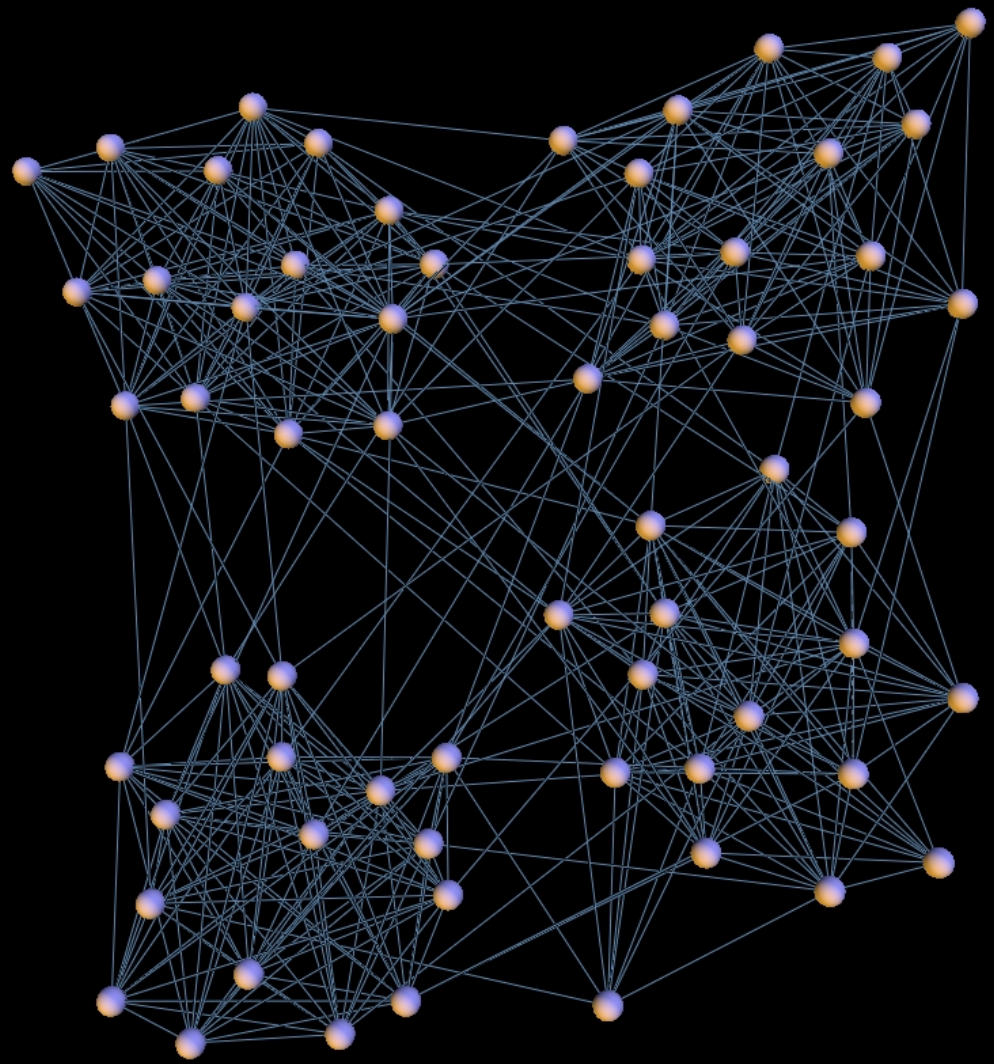
REAL PROTEOME:

<k>=2.4
© = 2.5
C = 0.7
D = 6.81
Disassortative
Modular
Hierarchical



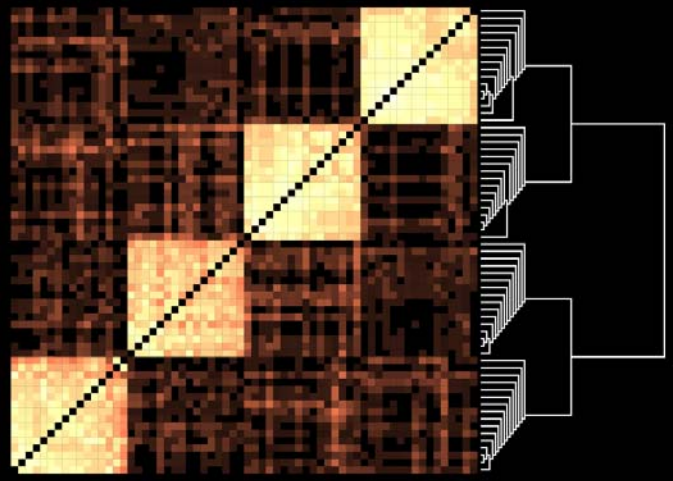
Evolving protein interaction networks through gene duplication
R. Pastor-Satorras, E. Smith and R. V. Solé
***J. Theor. Biol.* 222 (2003) 199-210**

Modular networks



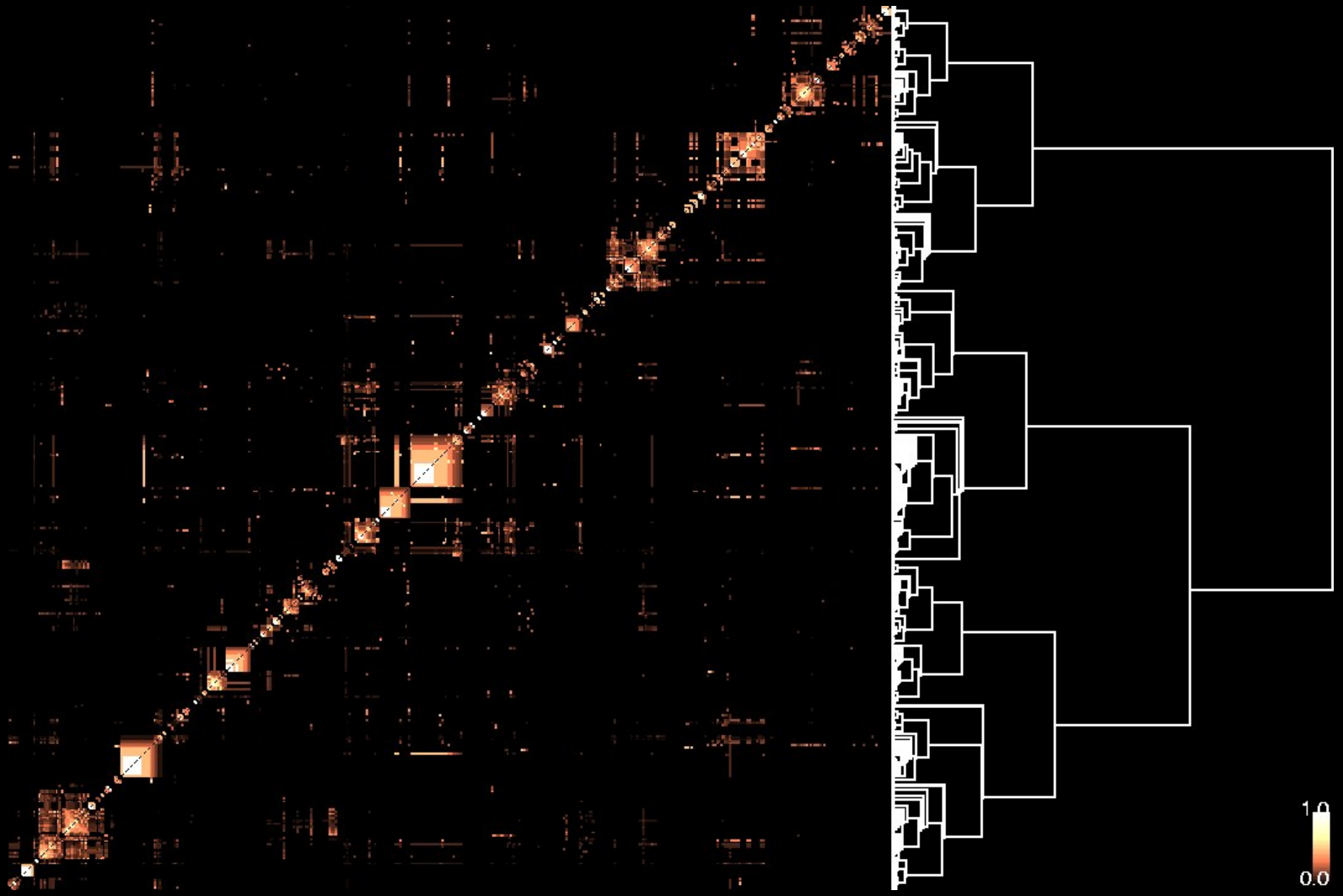
E. Ravasz, A. L. Somera, D. A. Mongru, Z. N. Oltvai and A.-L. Barabási
Hierarchical Organization of Modularity in Metabolic Networks
Science **297**, 1551-1555 (2002).

$$O(i,j) = \frac{J(i,j)}{\mathrm{Min}\{k(i),k(j)\}}$$



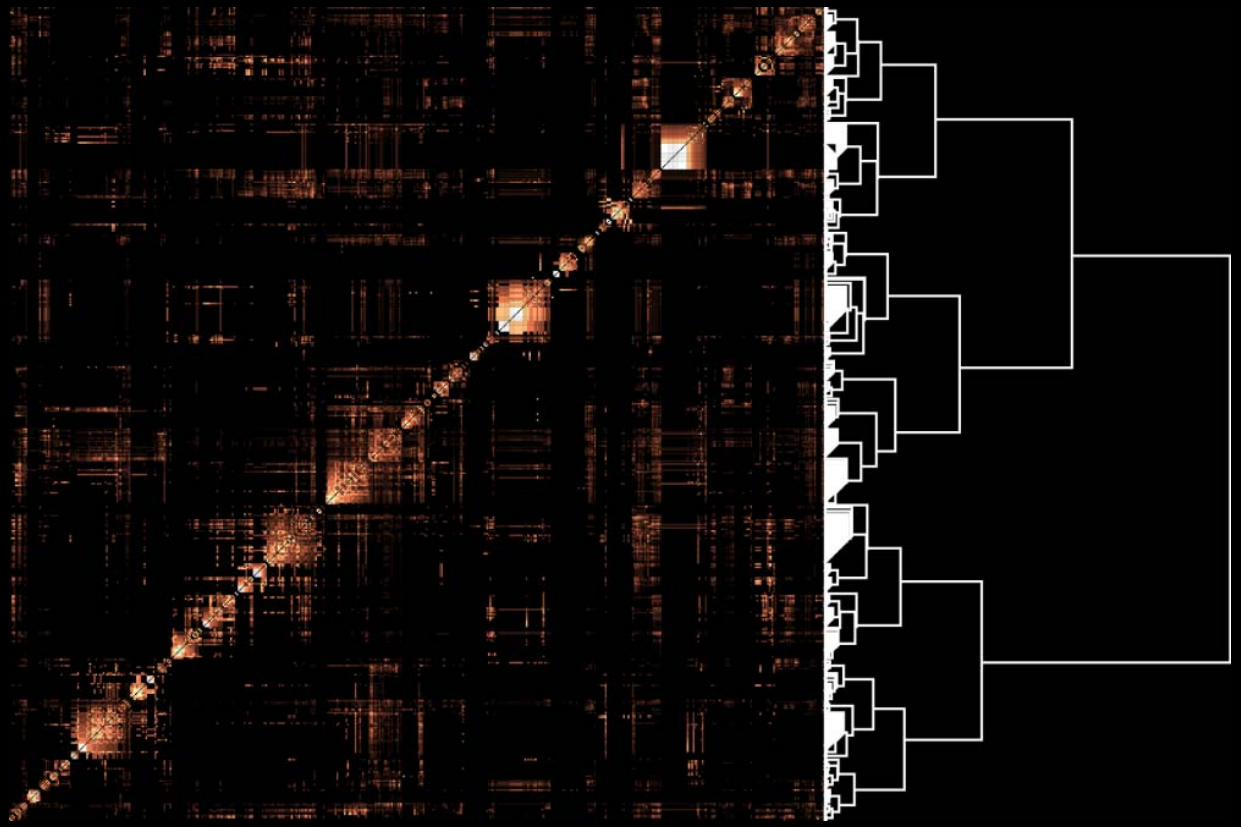
Overlap map

Cellular networks are modular



Modular architecture of the yeast interaction map

Modularity *for free?*



Spontaneous emergence of modularity in cellular networks
R. V. Solé and S. Valverde, J. Roy. Soc. Interface 2007
Are network motifs the spandrels of cellular complexity?
R. V. Solé and S. Valverde, Trends Ecol. Evol. 2006

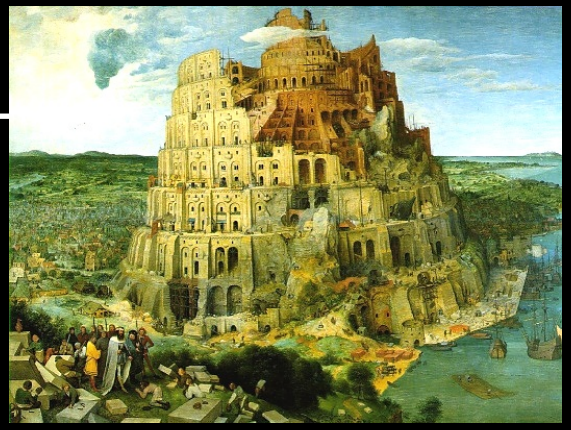
Language

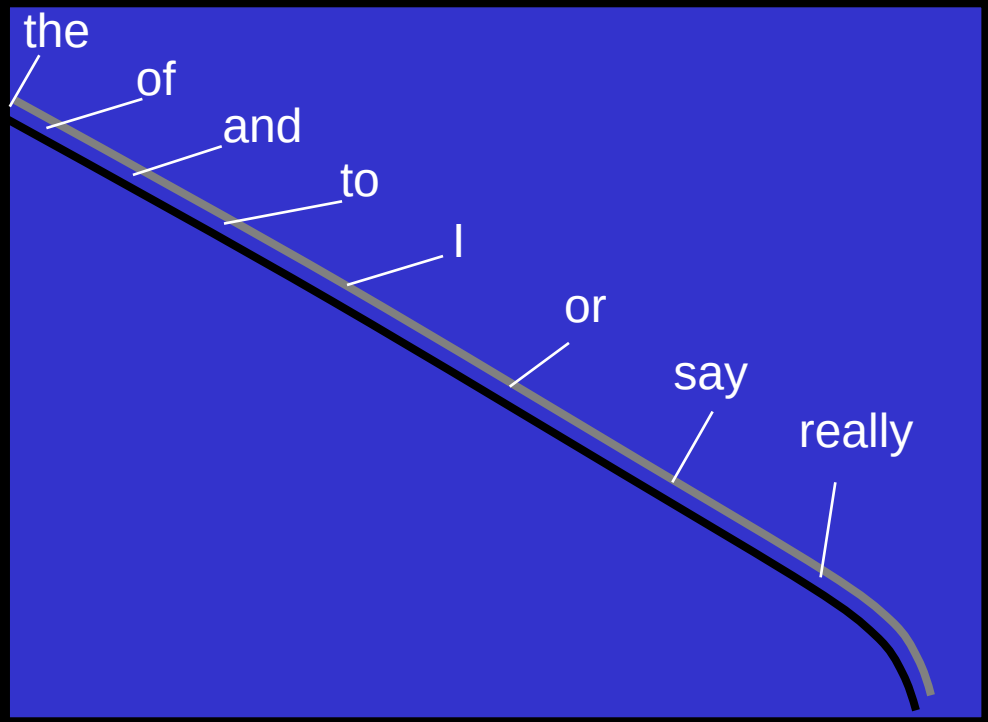
What is the topology of language networks?

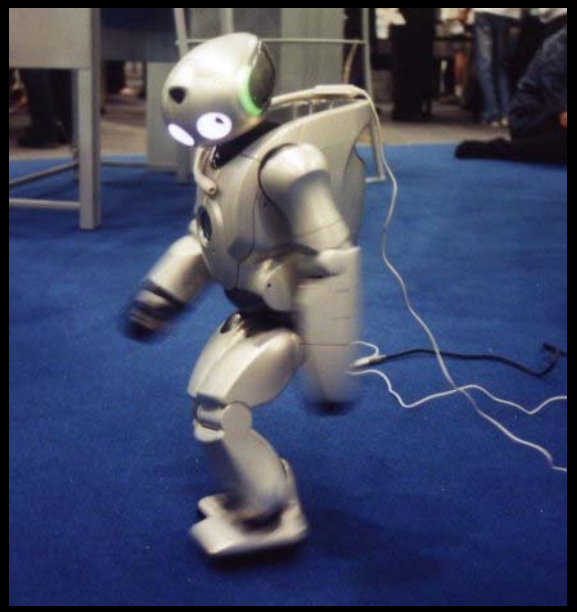
What are the consequences?

What are the origins?

Language universals







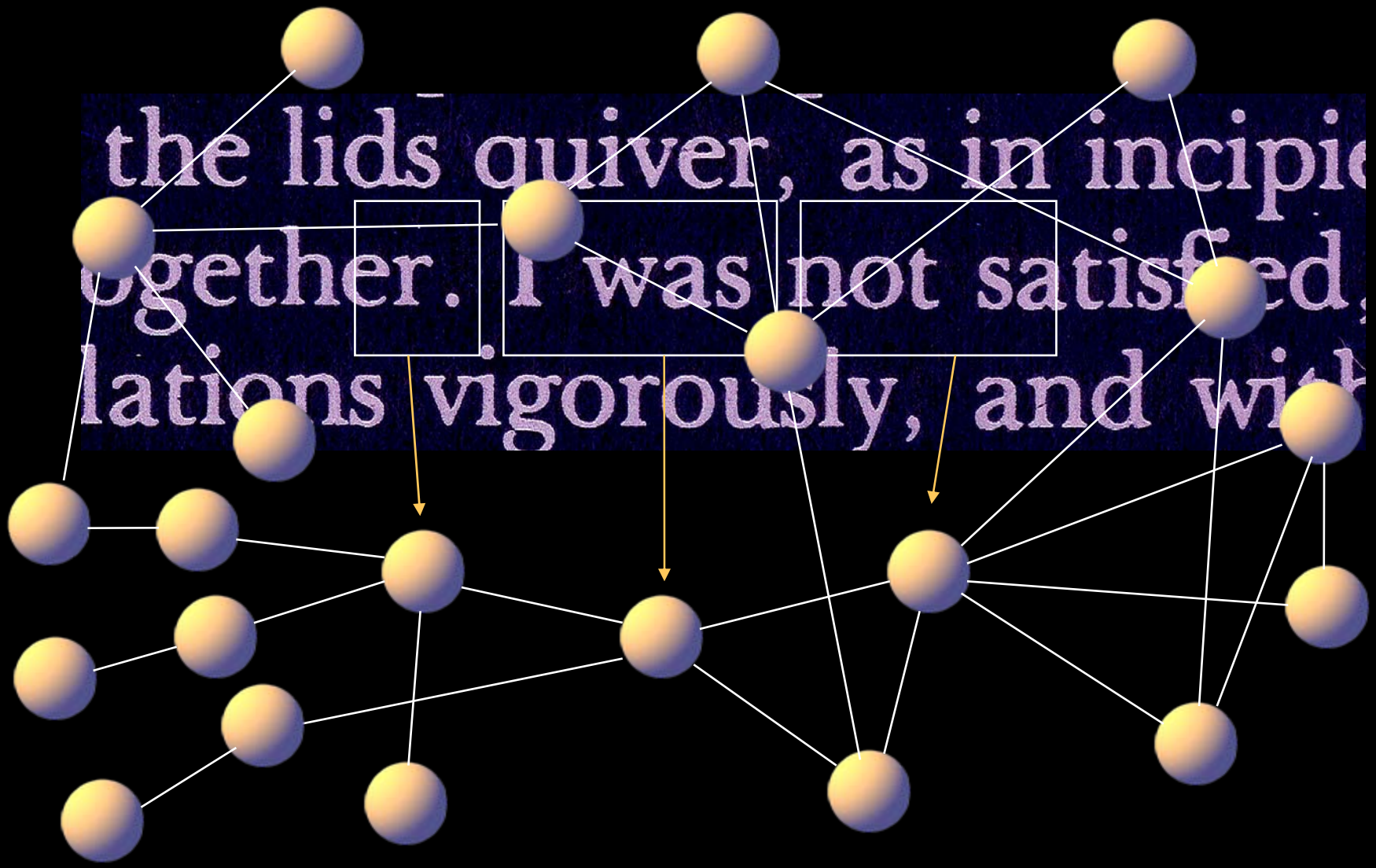
Zipf's law: all languages display it, why?
R. Ferrer and R. Solé, PNAS (2003)

Network of word co-occurrences

At five minutes before eleven I perceived unequivocal signs of the mesmeric influence. The glassy roll of the eye was changed for that expression of uneasy *inward* examination which is never seen except in cases of sleep-waking, and which it is quite impossible to mistake. With a few rapid lateral passes I made the lids quiver, as in incipient sleep, and with a few more I closed them altogether. I was not satisfied, however, with this, but continued the manipulations vigorously, and with the fullest exertion of the will, until I had completely stiffened the limbs of the slumberer, after placing them in a seemingly easy position. The legs were at full length; the arms were nearly so, and reposed on the bed at a moderate distance from the loins. The head was very slightly elevated.

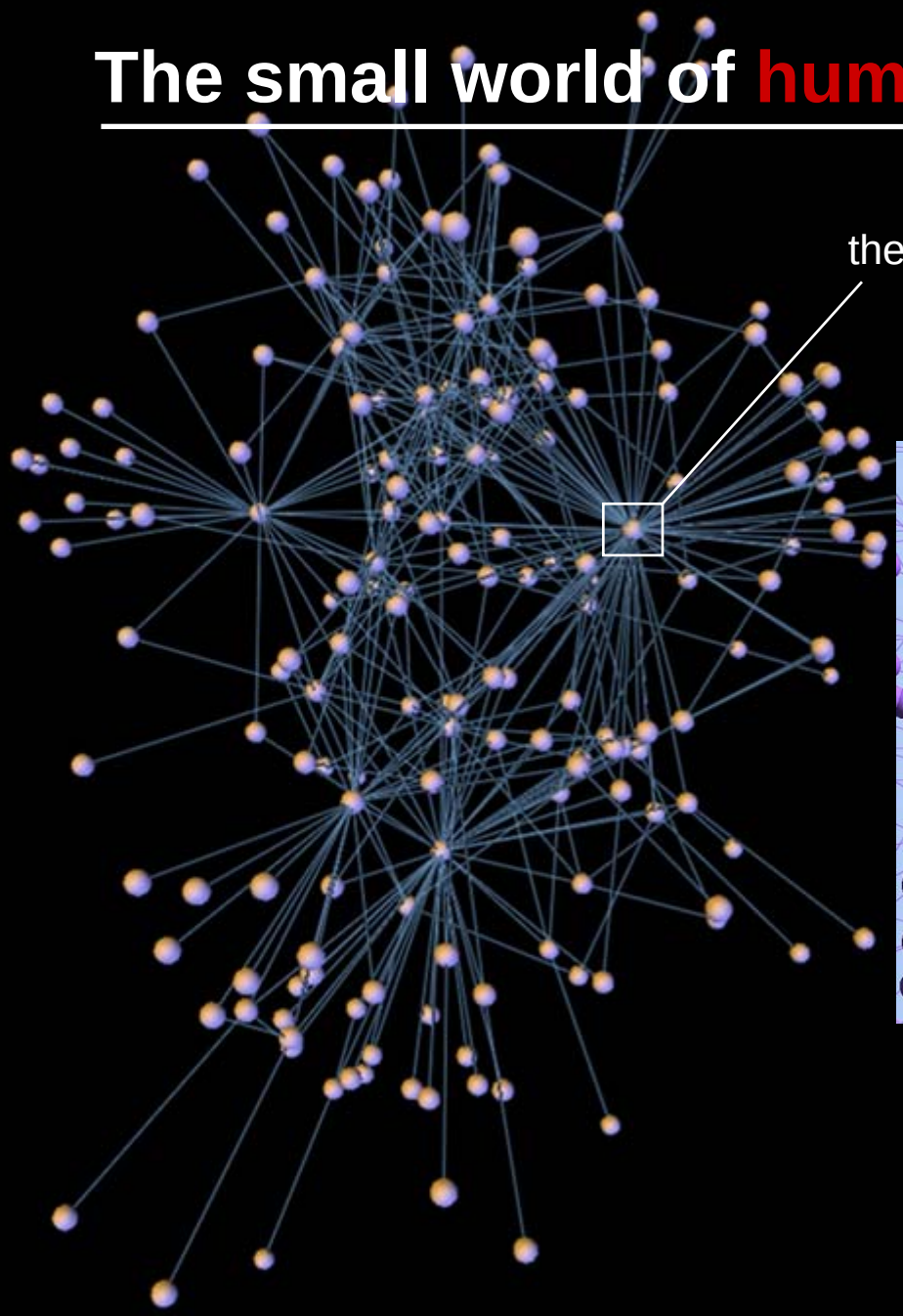
When I had accomplished this, it was fully midnight, and I requested the gentlemen present to examine M. Valdemar's condition. After a few experiments, they admitted him to be in an unusually perfect state of mesmeric trance. The curiosity of both the physicians was greatly excited.

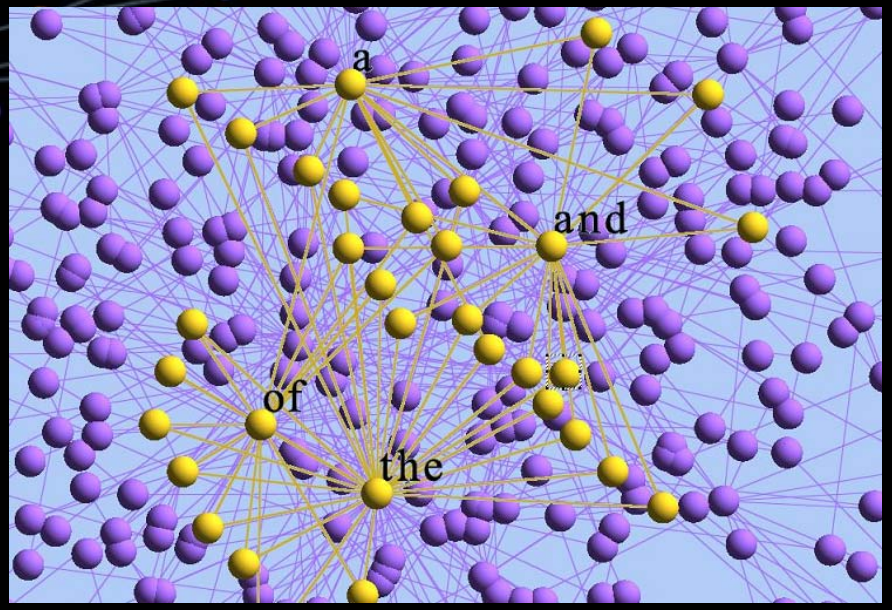
Network of word co-occurrences



The small world of human language

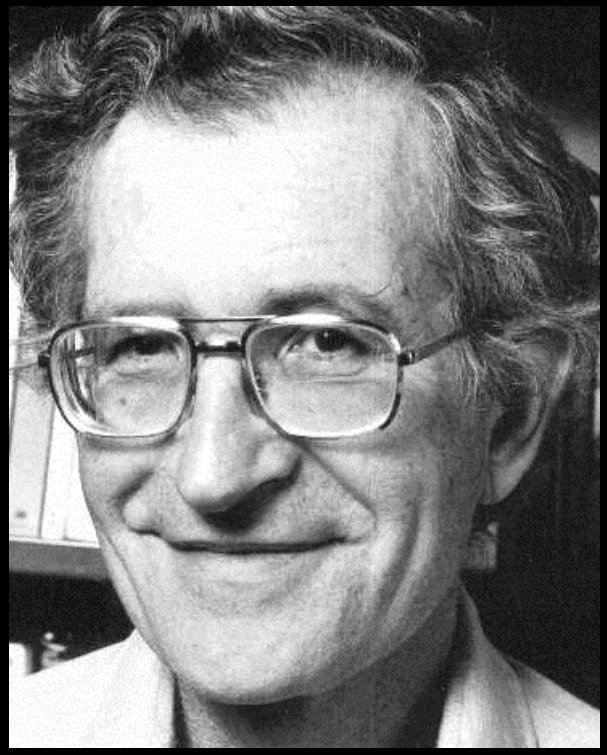
Less than 3 words in a universe of 50000-100000 words: L=2.5

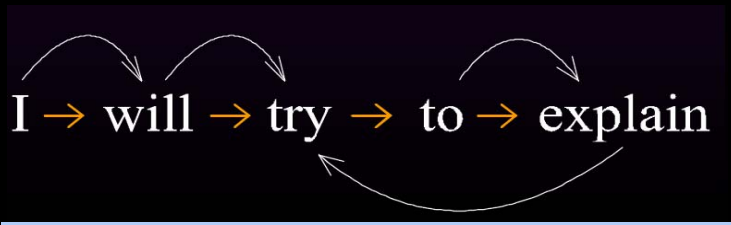


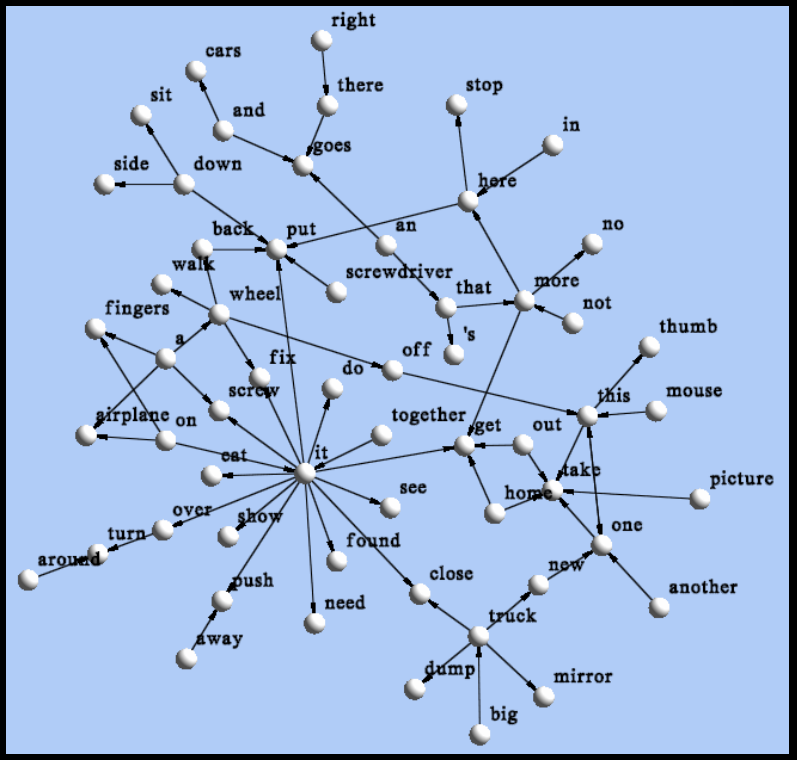


“The small world of human language”
R. Ferrer and R.V.Solé
Proc.Roy.Soc.London B (2002)

The ontogeny of human language



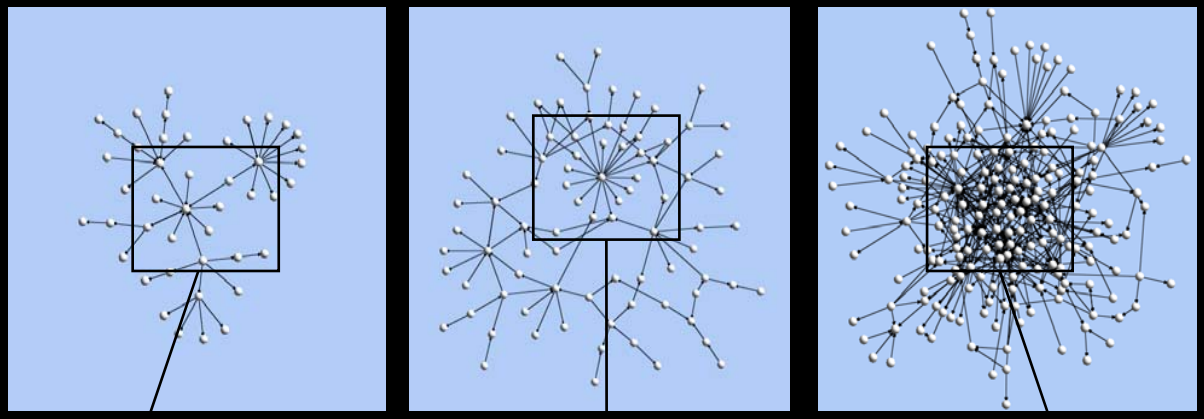


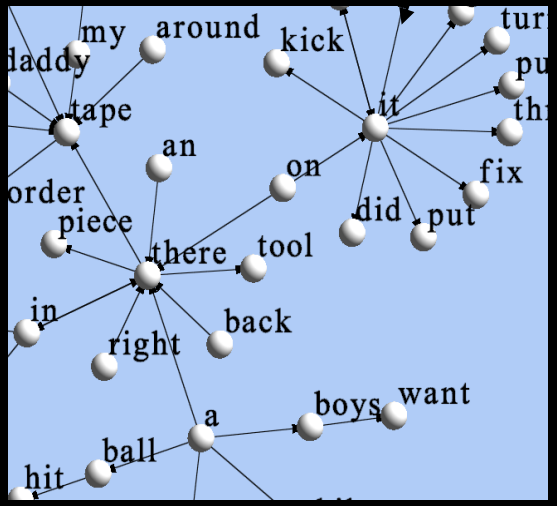


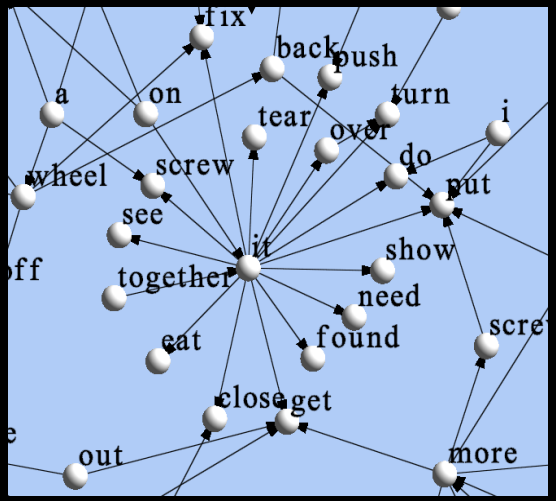
The SN provides a global, coarse picture of syntactic organization.
How do syntax networks change through language development?

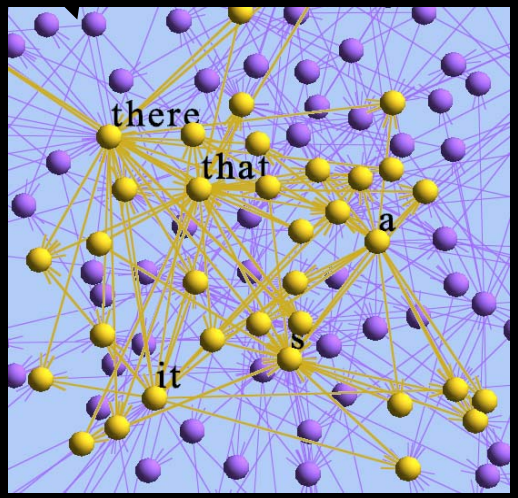
Language acquisition: the innate element

A sudden shift is observed at two years of age: networks experience a dramatic topological change, from tree-like to scale free









Emergence of scale-free syntax networks, B. Corominas, S. Valverde and RS
arXiv:0709.4344v [q-bio.NC] 27 Sep 2007

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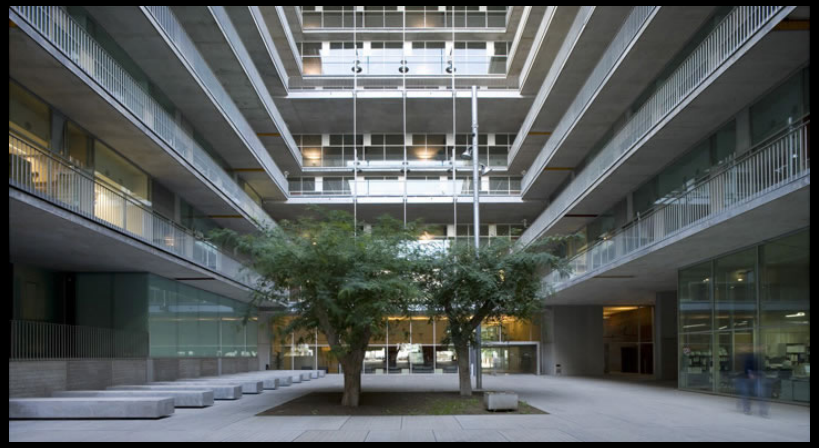

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