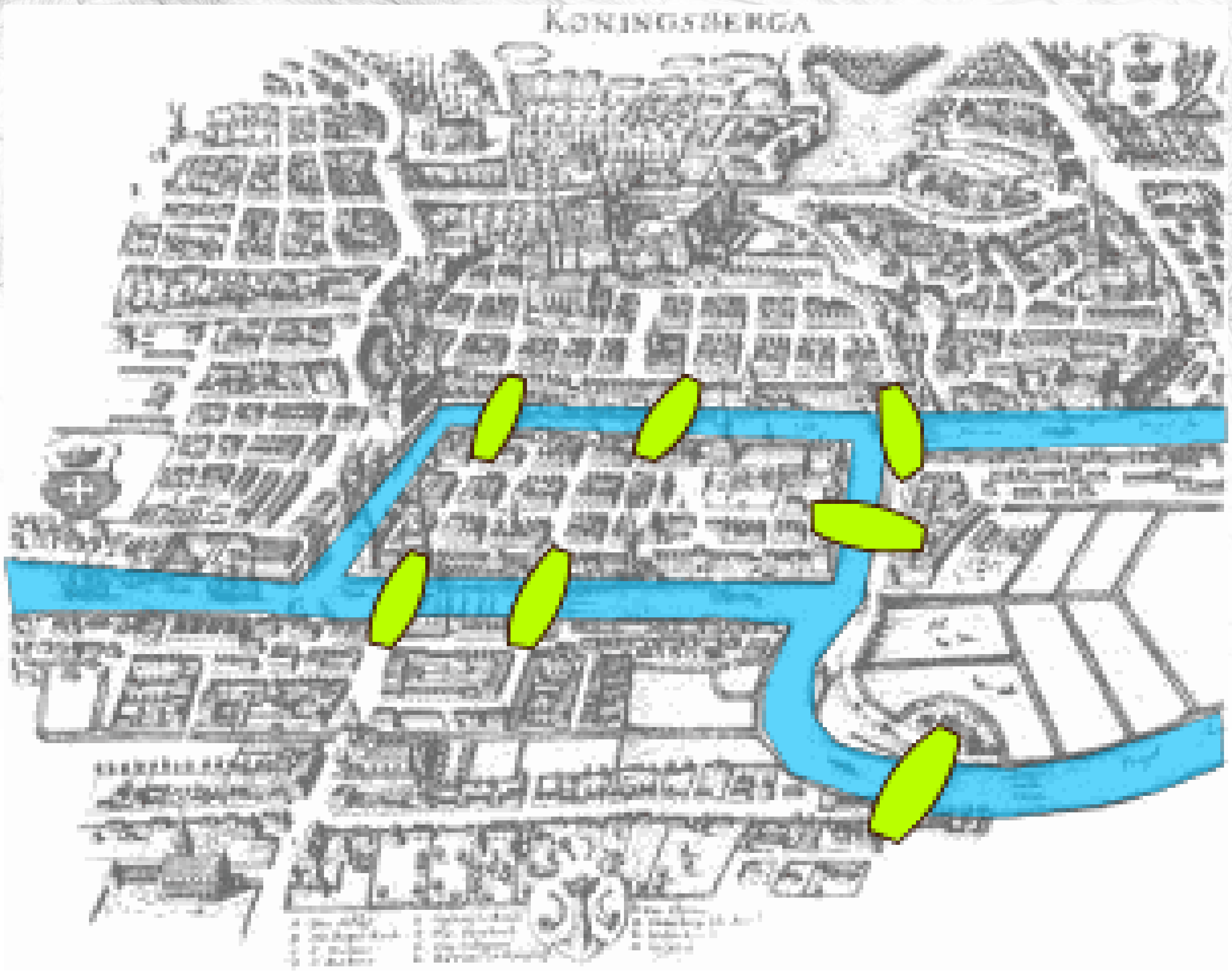
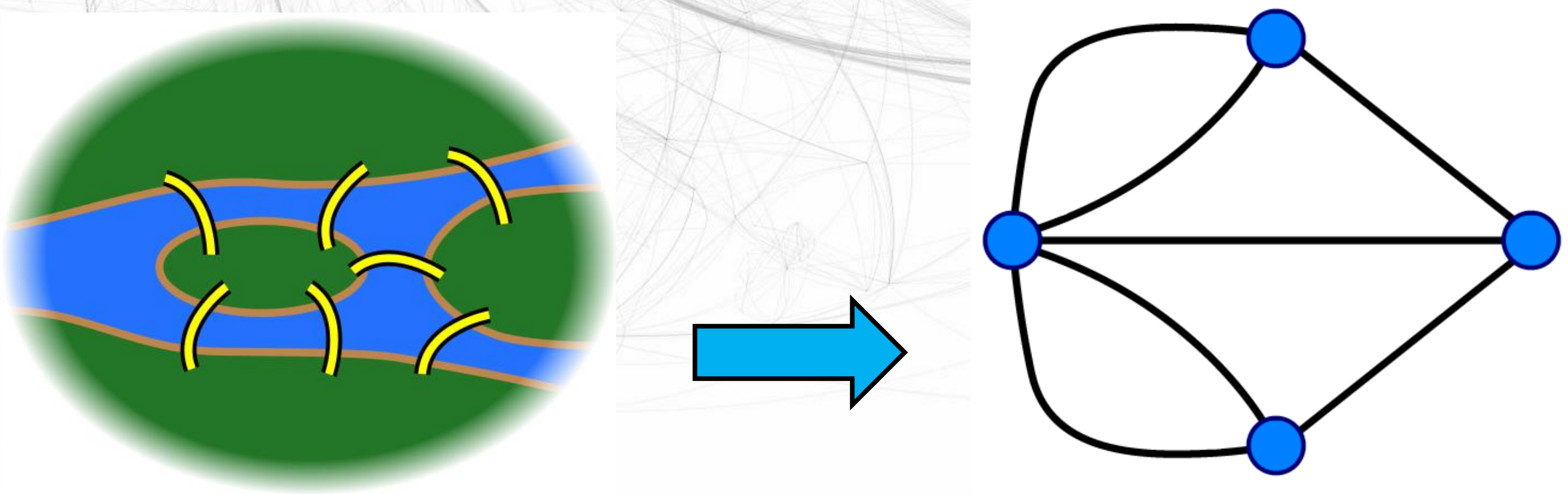
Introduction to network theory

Why ‘n How
March 7th, 2013
Linda Douw

http://www.youtube.com/watch?v=eAXVa__XWZ8

Euler in Kalinigrad

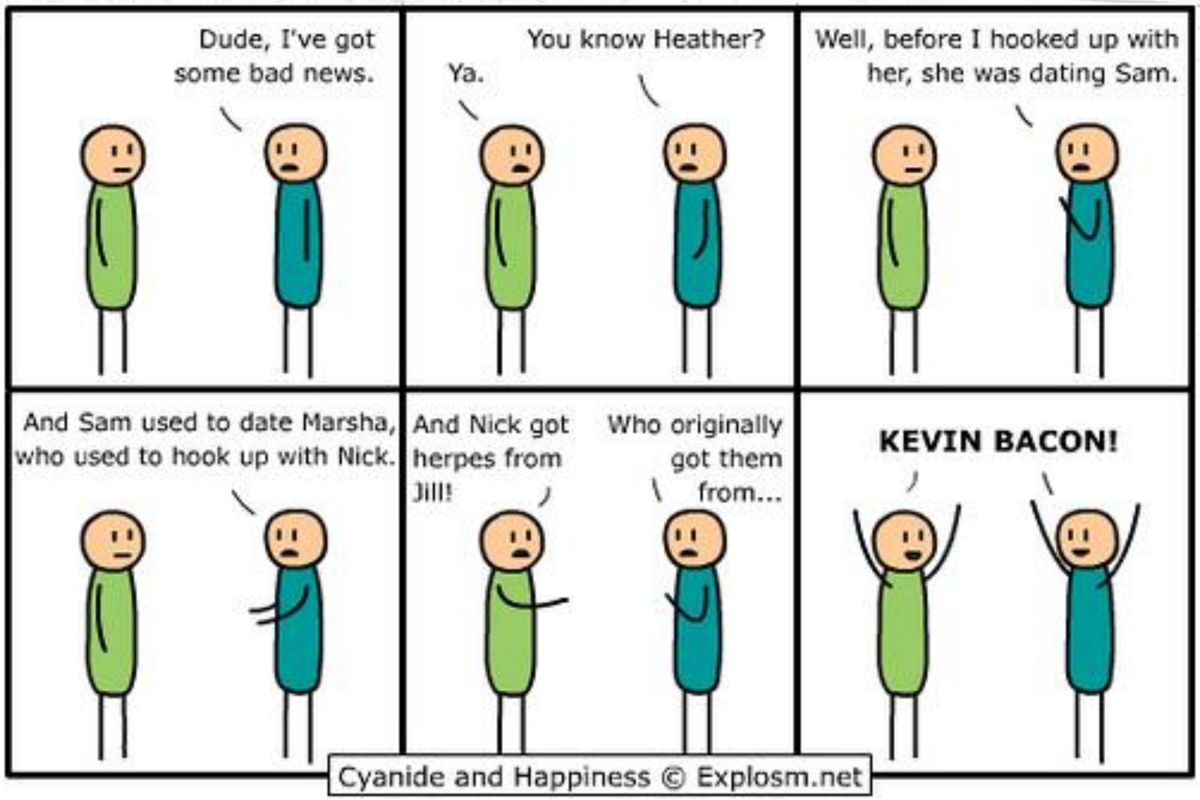




Six degrees of separation

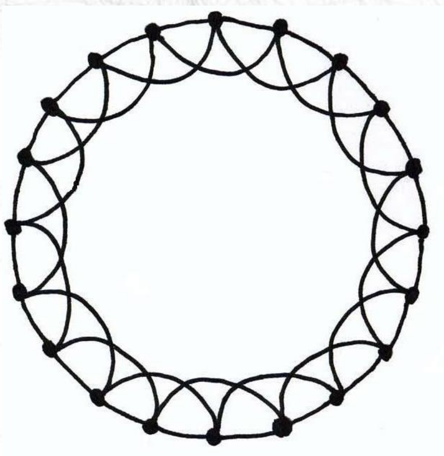
Stanley Milgram

small world experiment, 1967



The small world

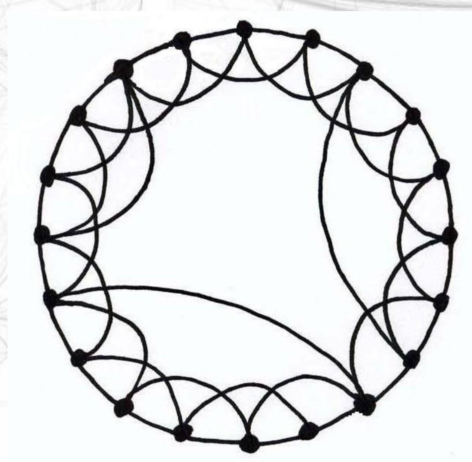
Regular



High C

High L

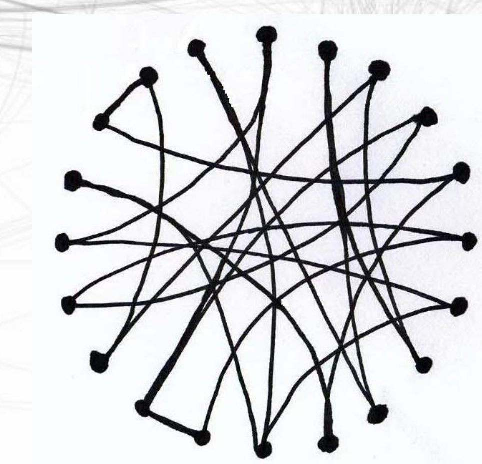
Small-world



High C

Low L

Random

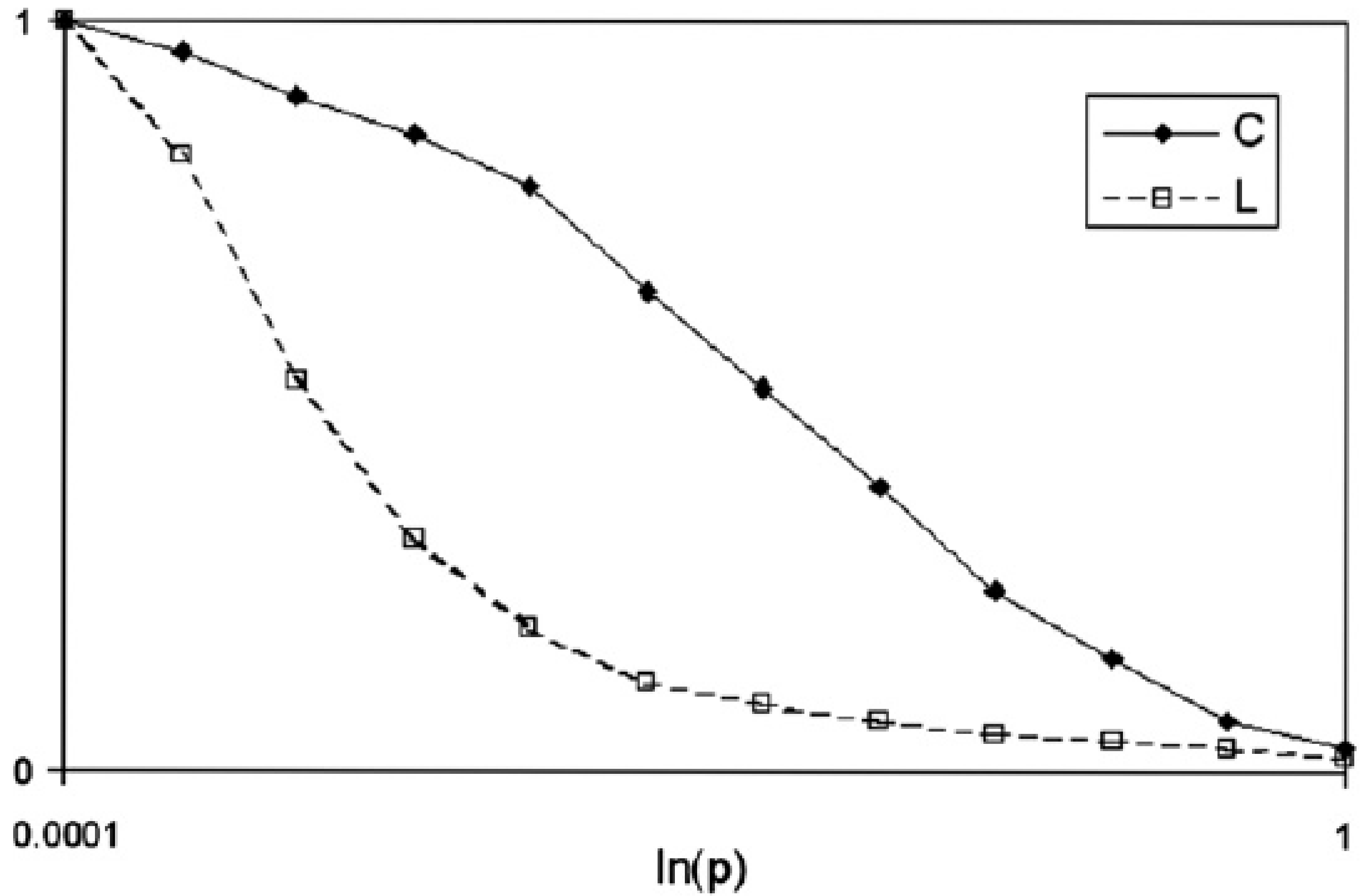


Low C

Low L

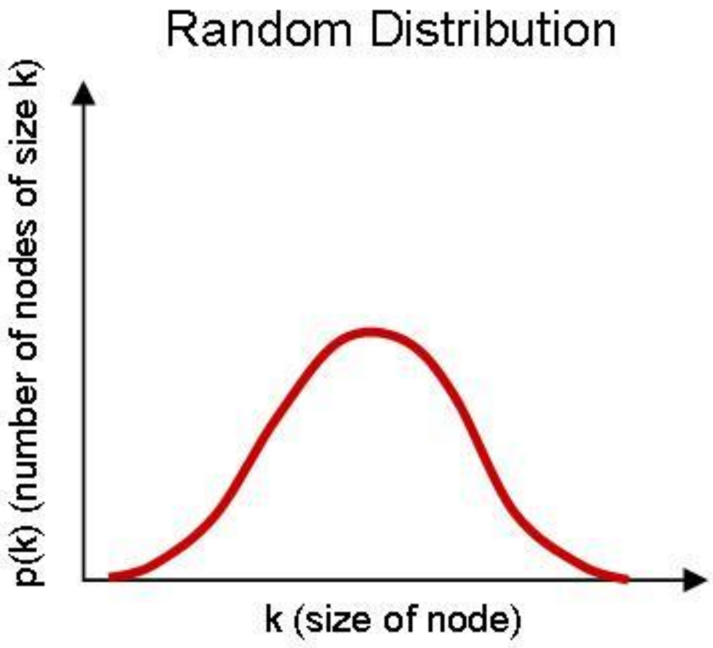
Watts & Strogatz (1998)

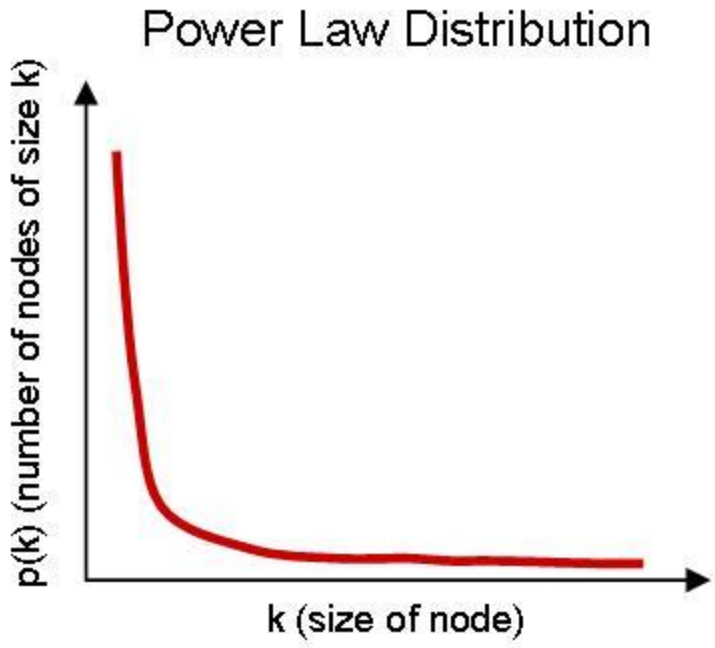
Rewiring a few connections makes a big difference



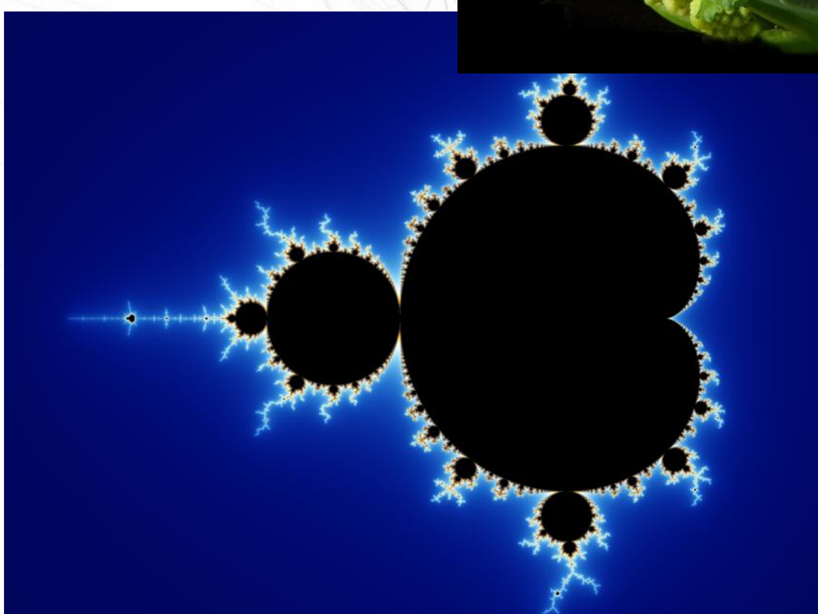
Watts & Strogatz (1998)

Scale-freedom

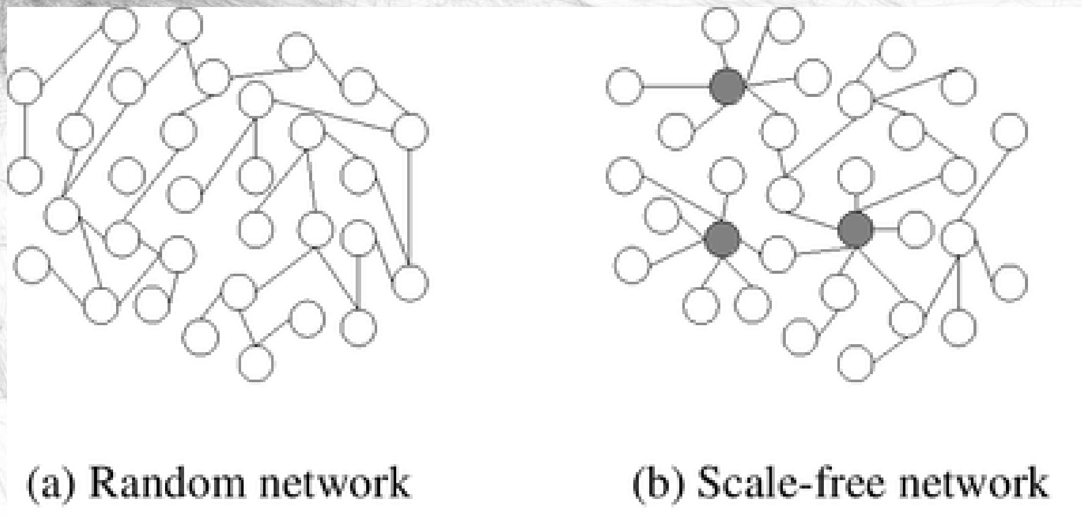


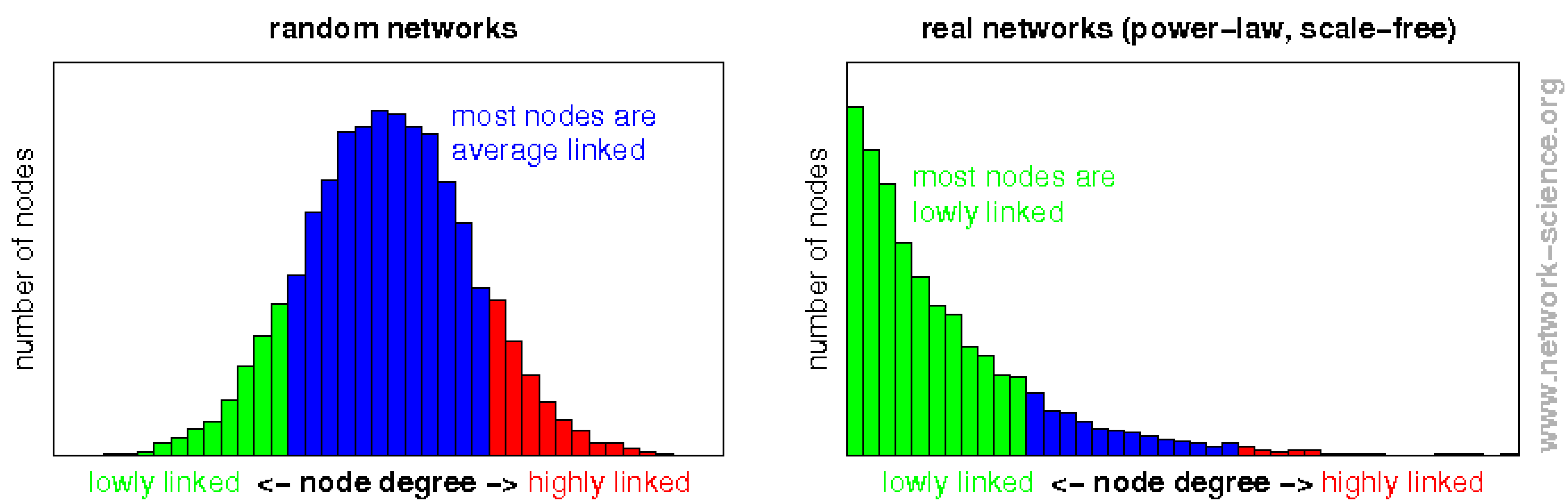


Scale-freedom

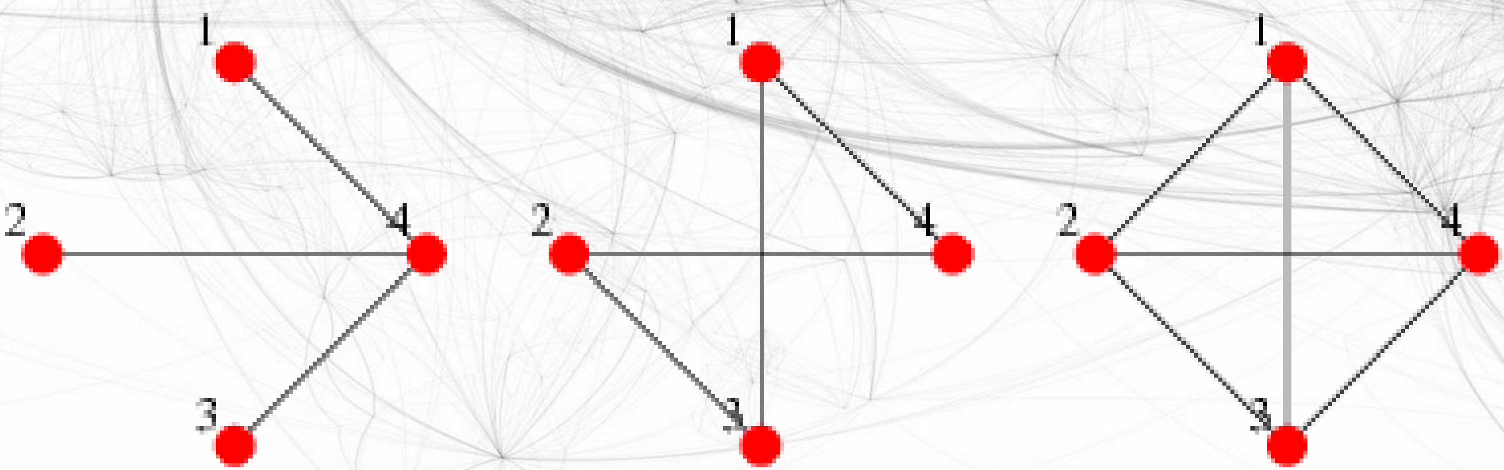


http://acko.net/blog/how-to-fold-a-julia-fractal/?second


(a) Random network
(b) Scale-free network

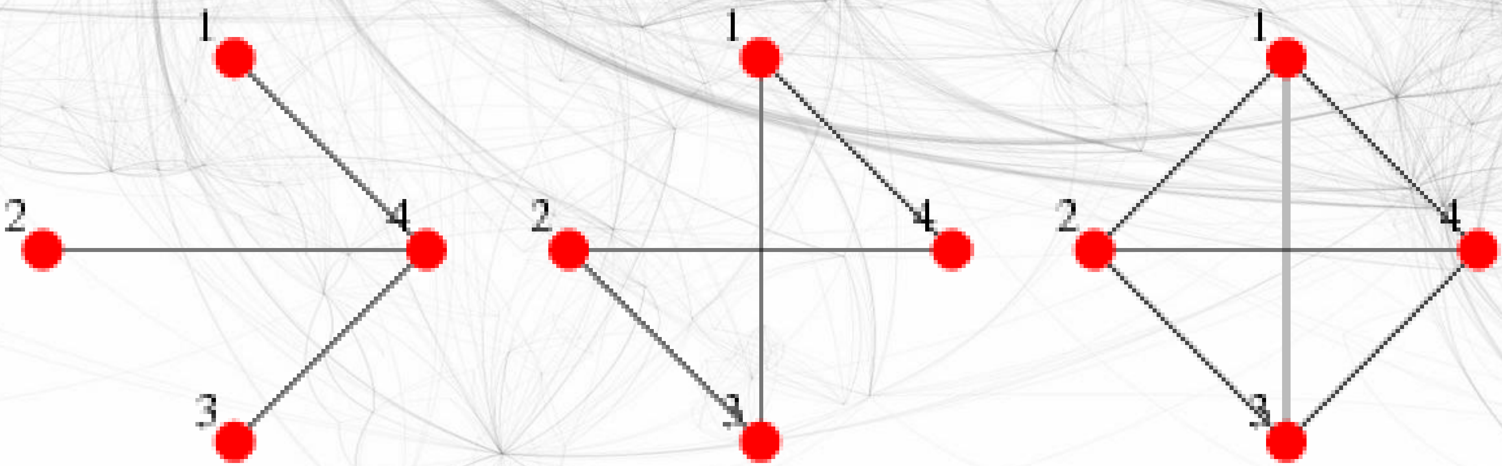

random networks
real networks (power-law, scale-free)
number of nodes
most nodes are
average linked
most nodes are
lowly linked
lowly linked
<- node degree -> highly linked
www.network-science.org

Adjacency matrix



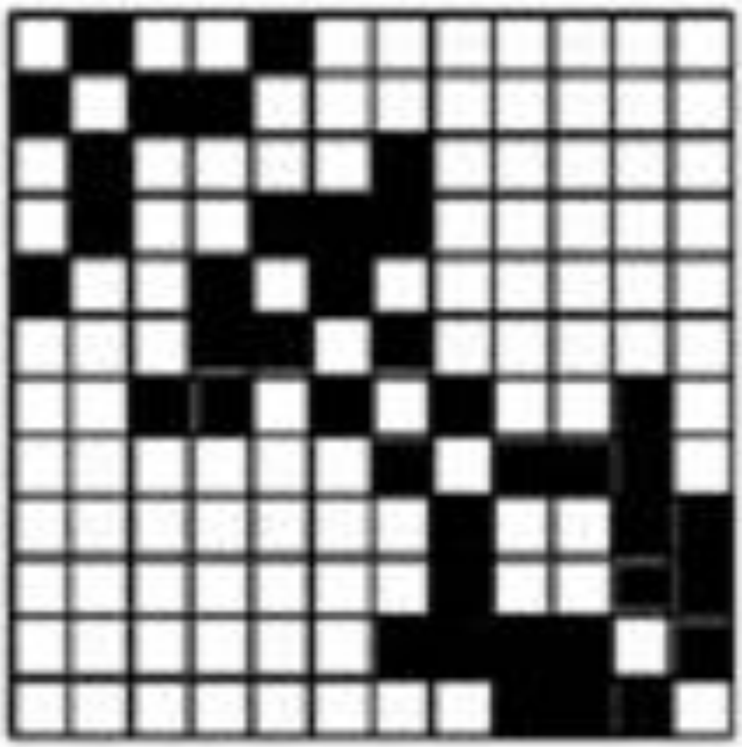
$$\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix} \qquad \begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix} \qquad \begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$

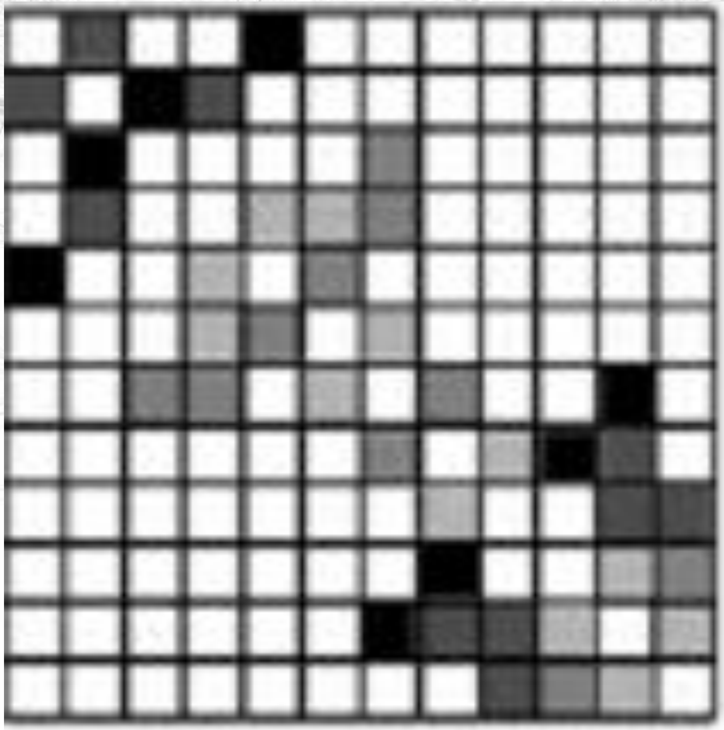
Degree



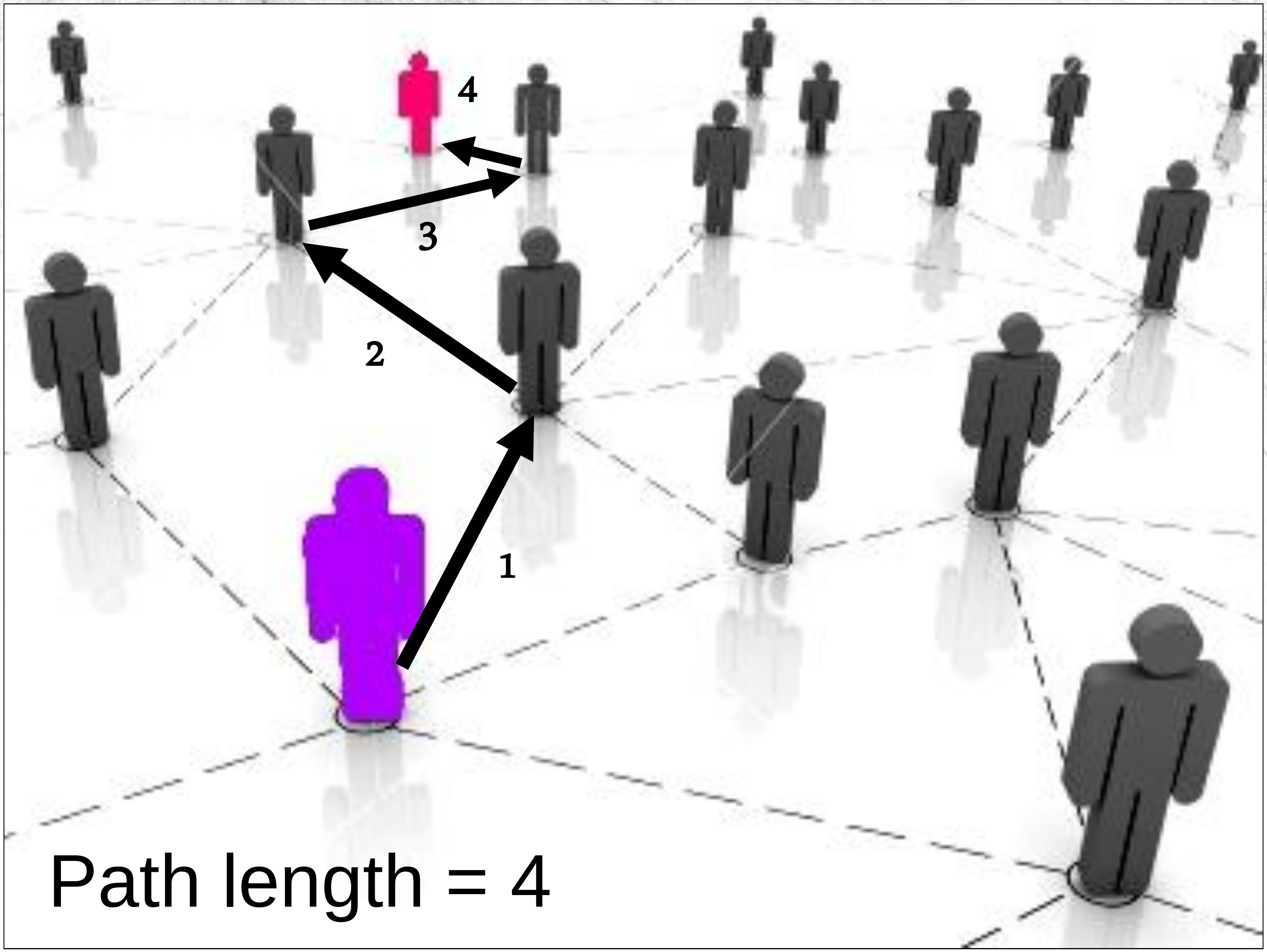
Degree of node 2?

Binary versus weighted



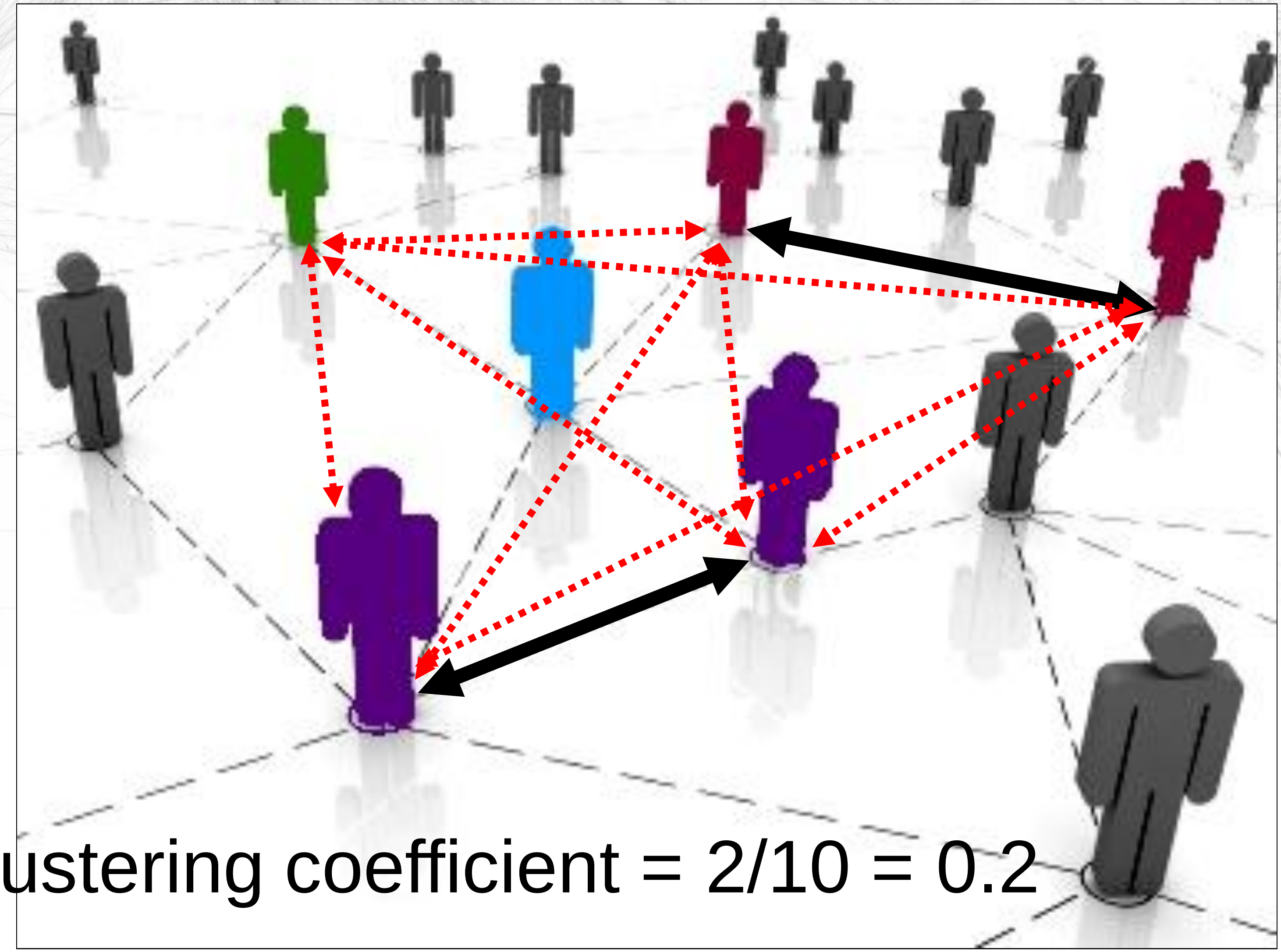


Path length


4
3
2
1
Path length = 4

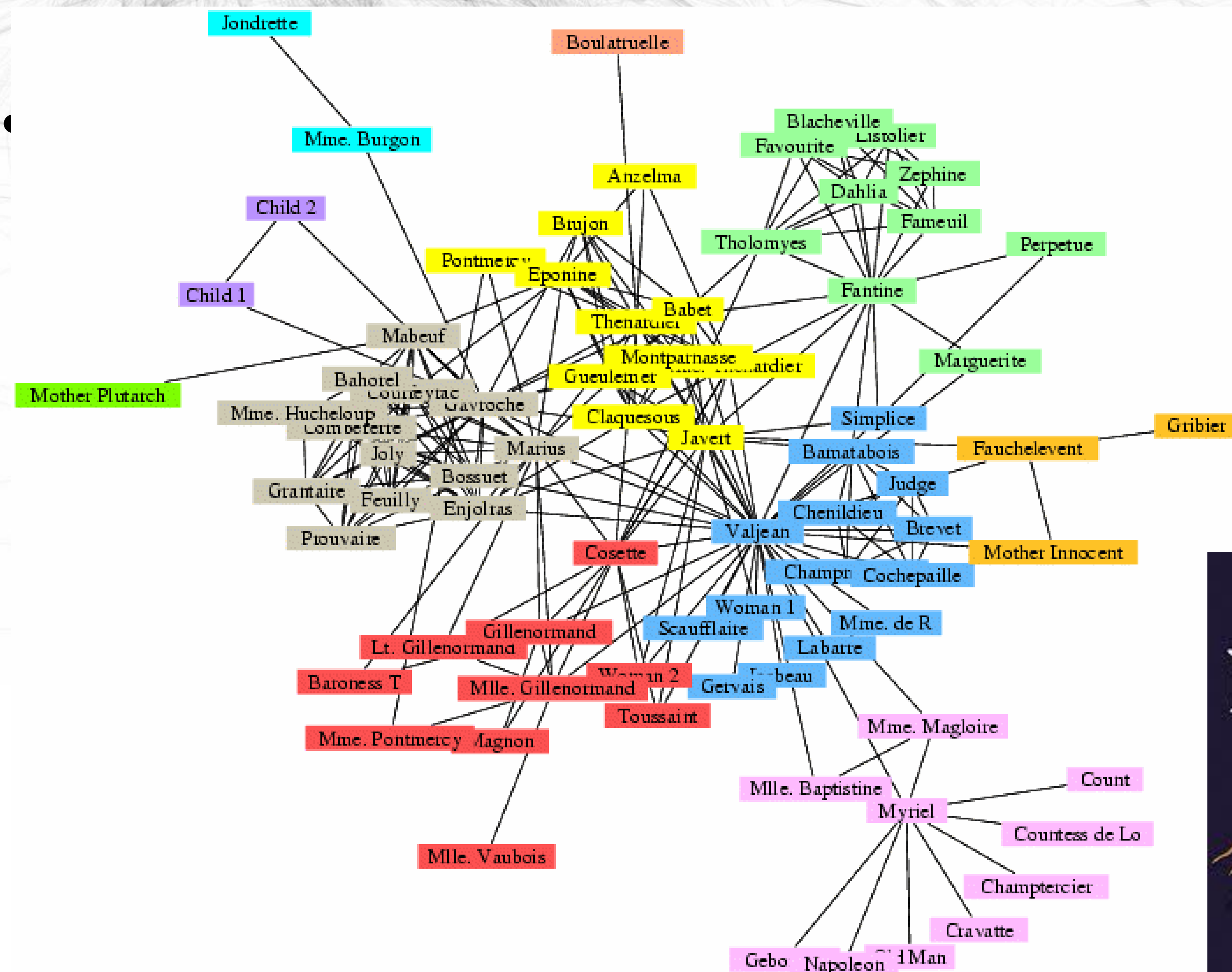
Clustering coefficient

Clustering coefficient

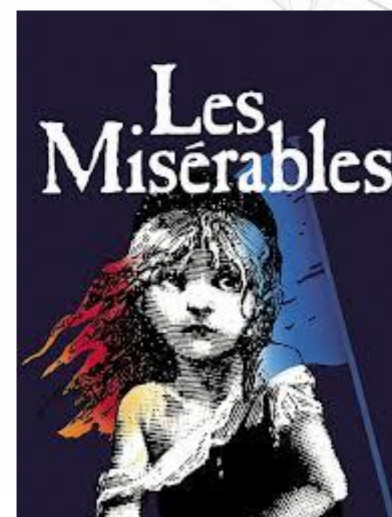


Clustering coefficient = 2/10 = 0.2

Modularity

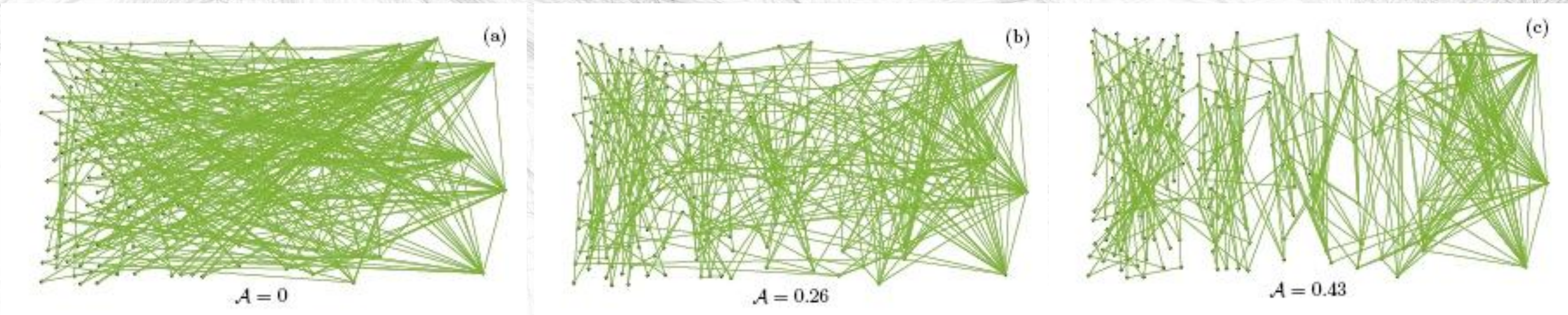


Jondrette
Boulatruelle
Mme. Burgon
Blacheville
Favourite
Anzelma
Zephine
Dahlia
Child 2
Brujon
Fameuil
Tholomyes
Perpetue
Eponine
Fantine
Child 1
Babet
Mabeuf
Montparnasse
Marguerite
Mother Plutarch
Bahorel
Gueulemer
Mme. Hucheloup
Claquesous
Simplice
Gribier
Joly
Javert
Marius
Bamatabois
Fauchelevent
Bossuet
Judge
Grantaire
Feuilly
Enjolras
Chenildieu
Valjean
Brevet
Prouvaire
Cosette
Mother Innocent
Cochepaille
Woman 1
Gillenormand
Scaufflaire
Mme. de R
Lt. Gillenormand
Labarre
Baroness T
Mlle. Gillenormand
Gervais
Toussaint
Mme. Magloire
Mme. Pontmercy
Count
Mlle. Baptistine
Myriel
Countess de Lo
Mlle. Vaubois
Champtercier
Cravatte
Gebo
Napoleon



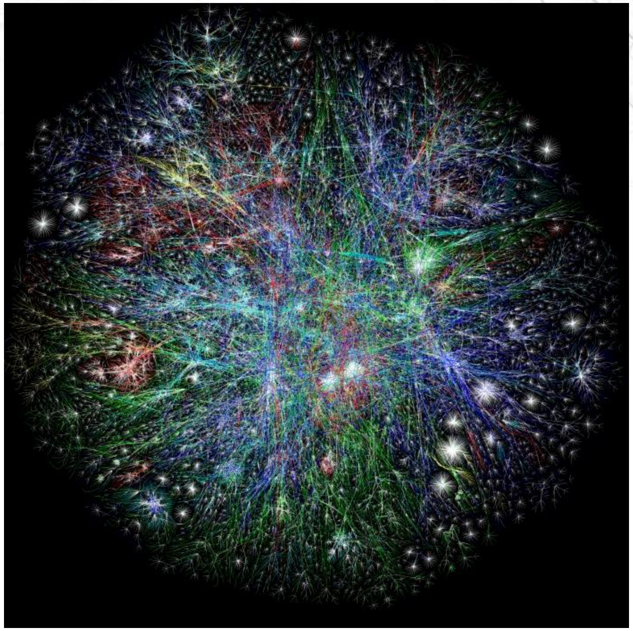
Les Misérables

Assortativity (related: rich-club)

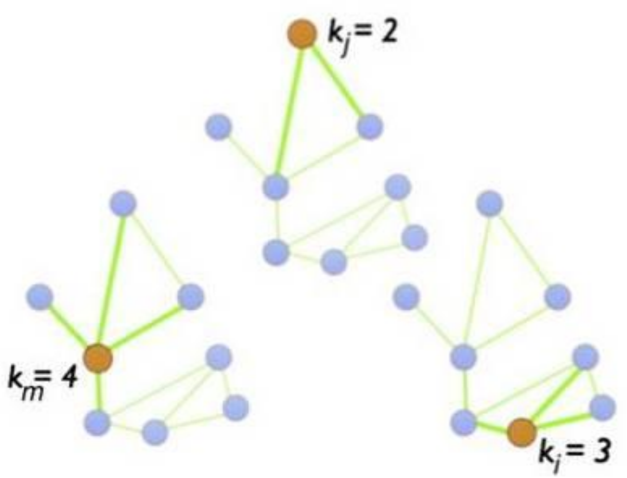


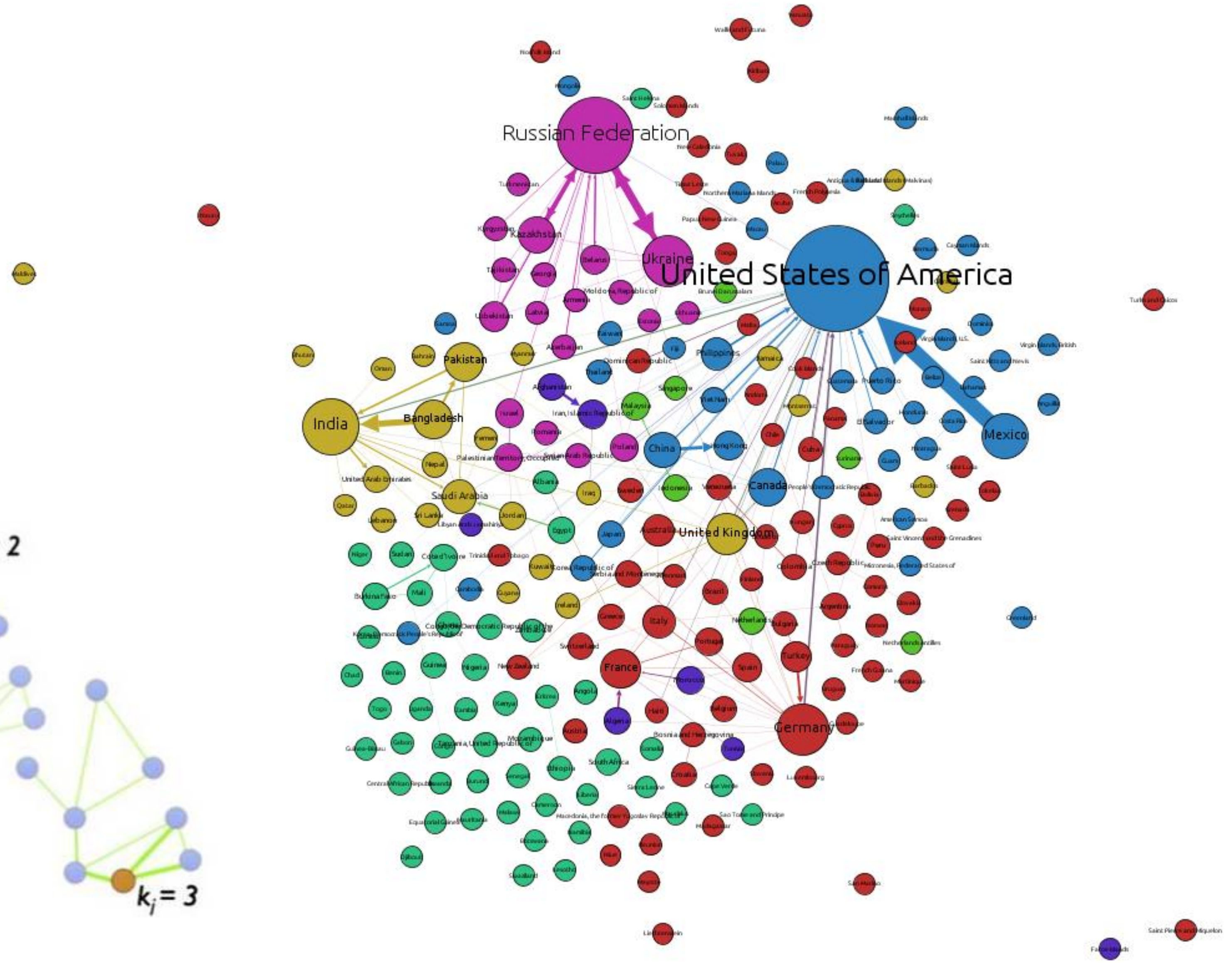
Assortative: Social network

Disassortative: Internet

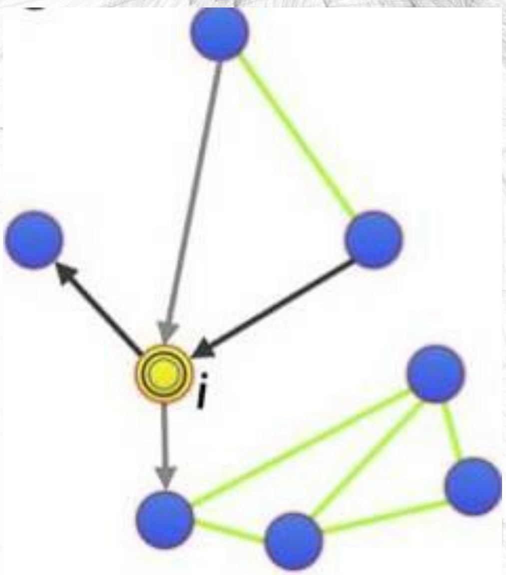


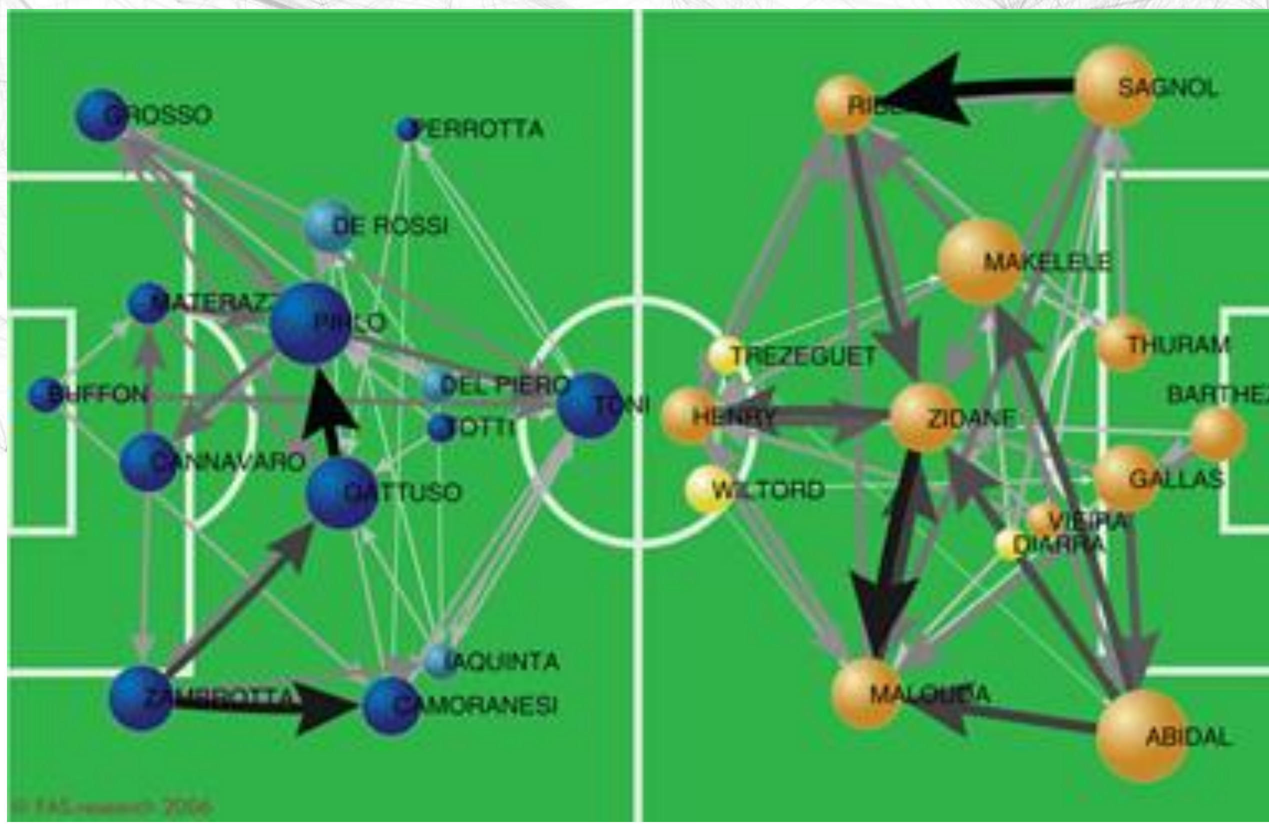
Hubs in immigration





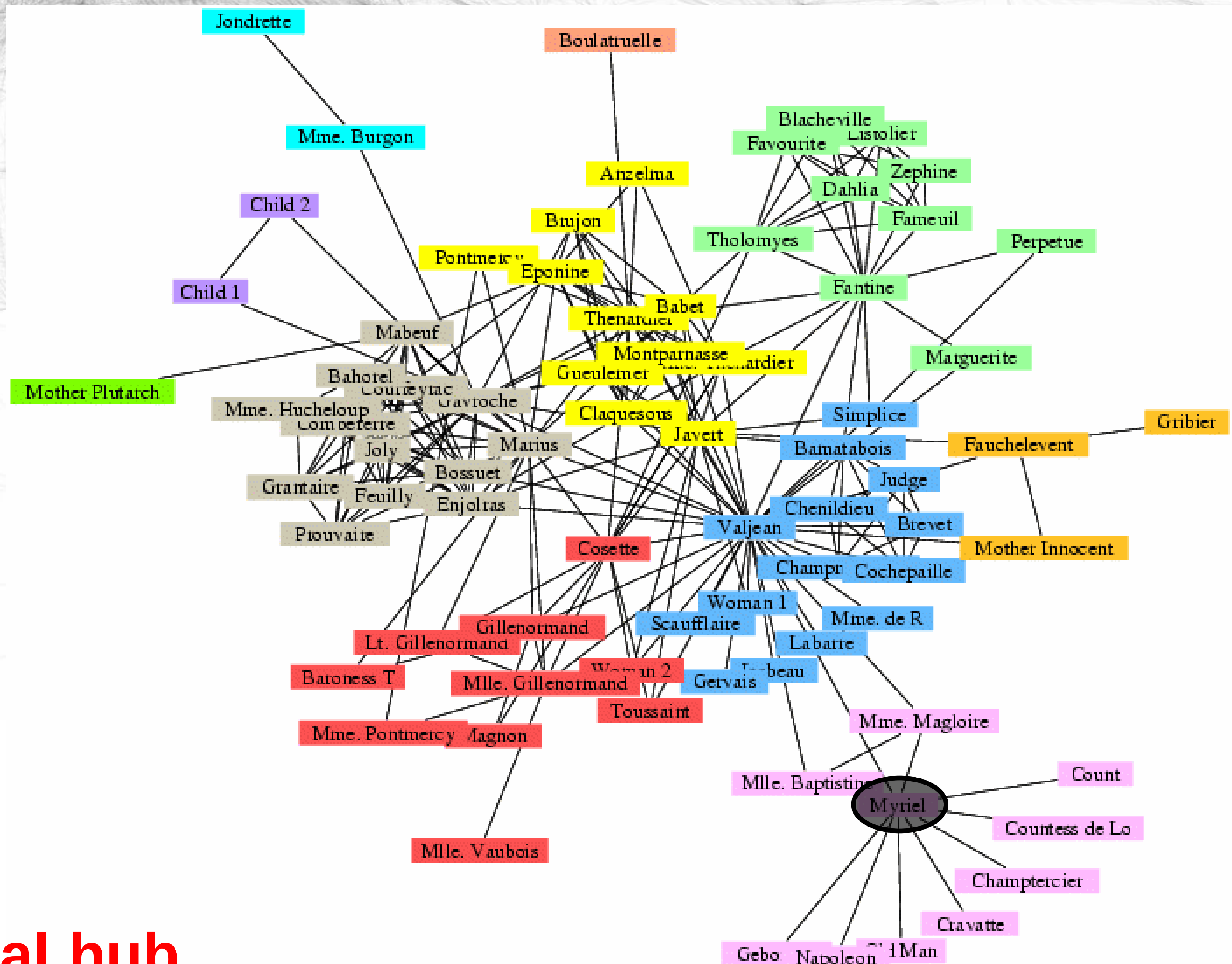
Betweenness centrality





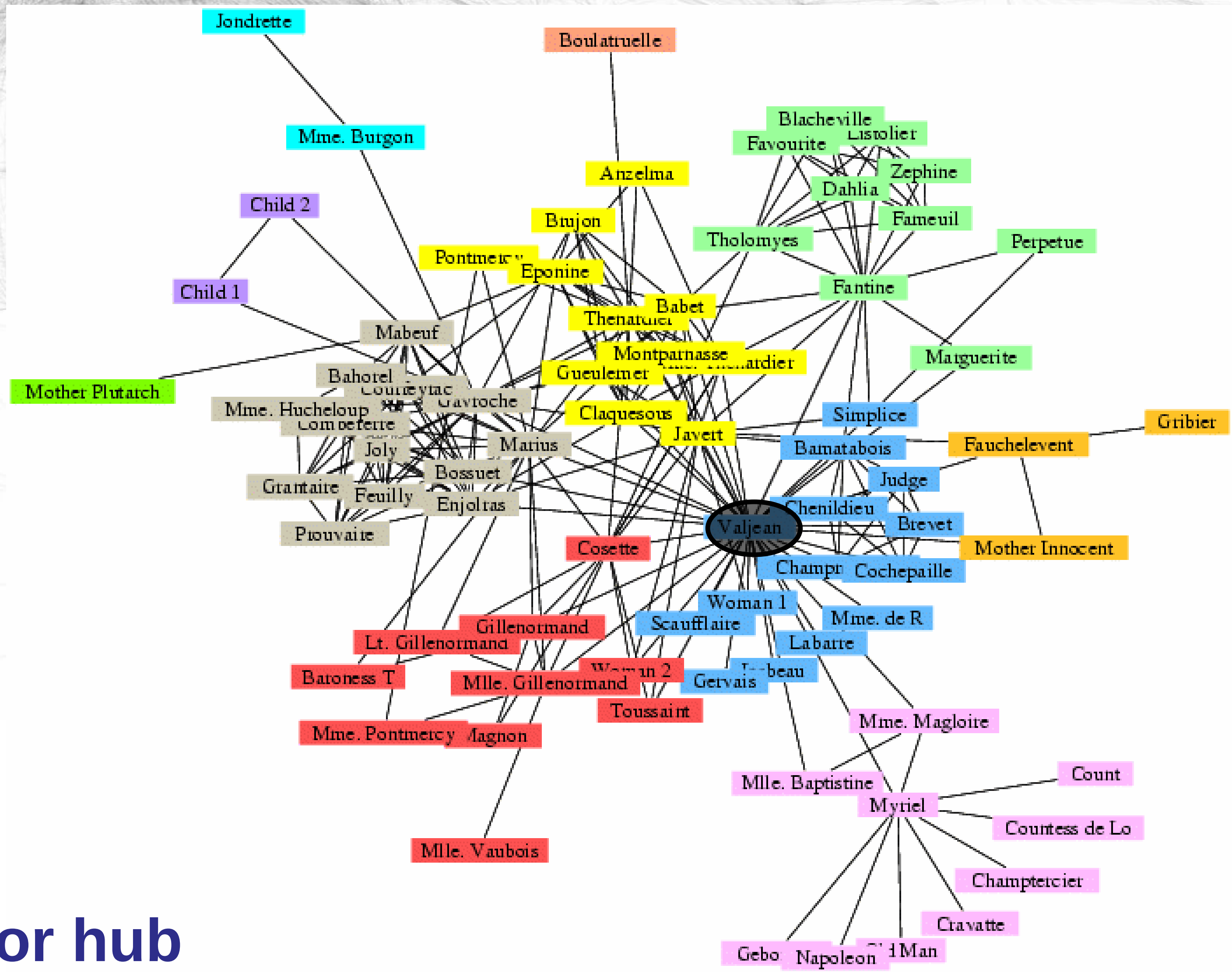
http://bladesofblue.blogspot.com/2007/05/data-visualization-world-cup-final.html

within-module connectivity (zi)



provincial hub
high zi

between-module connectivity (pc)

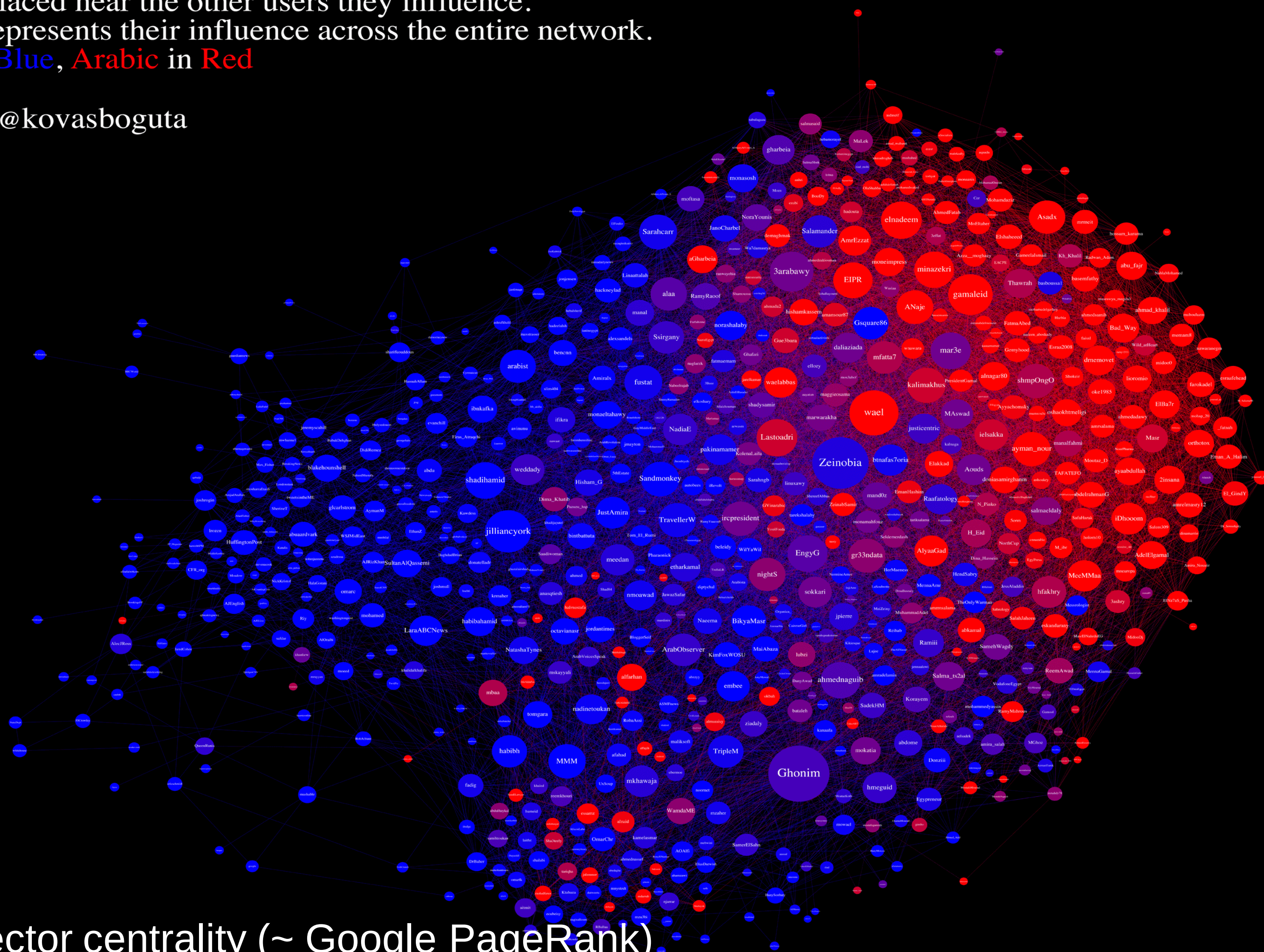


connector hub
high pc

Egypt Influence Network

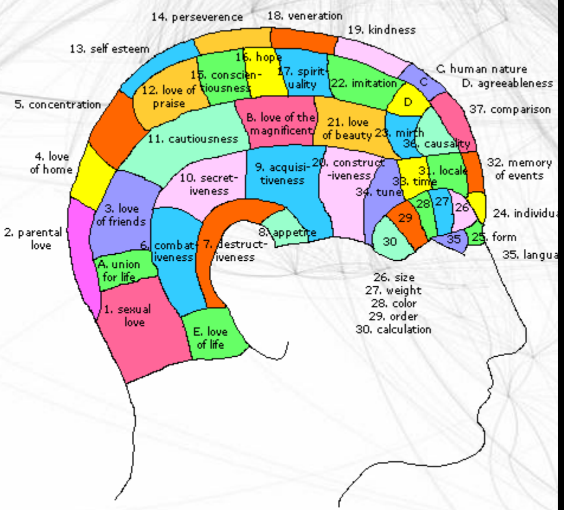
Twitter users are said to influence each other if they follow each other, shown with lines.
Users are placed near the other users they influence.
User size represents their influence across the entire network.
English in Blue, Arabic in Red

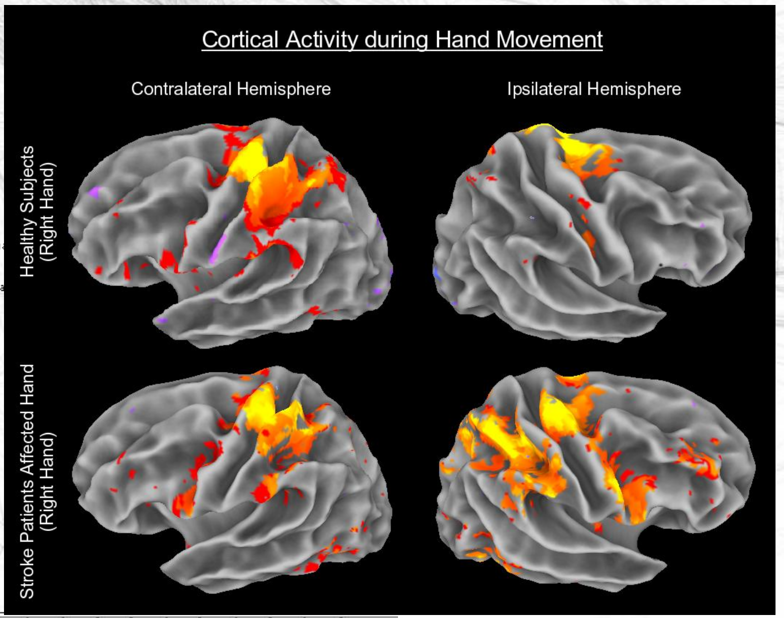
Follow me @kovasboguta

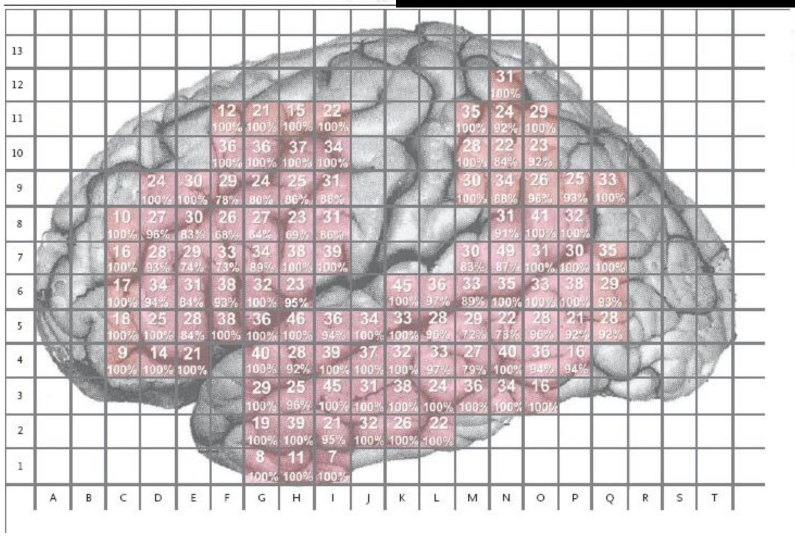


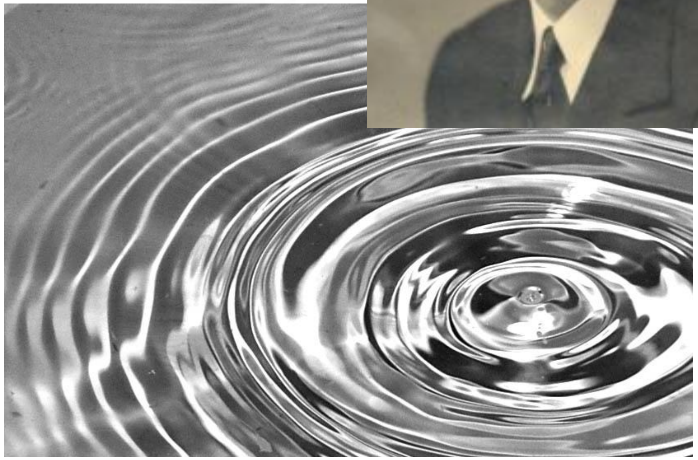
Eigenvector centrality (~ Google PageRank)

The brain: localization vs distribution

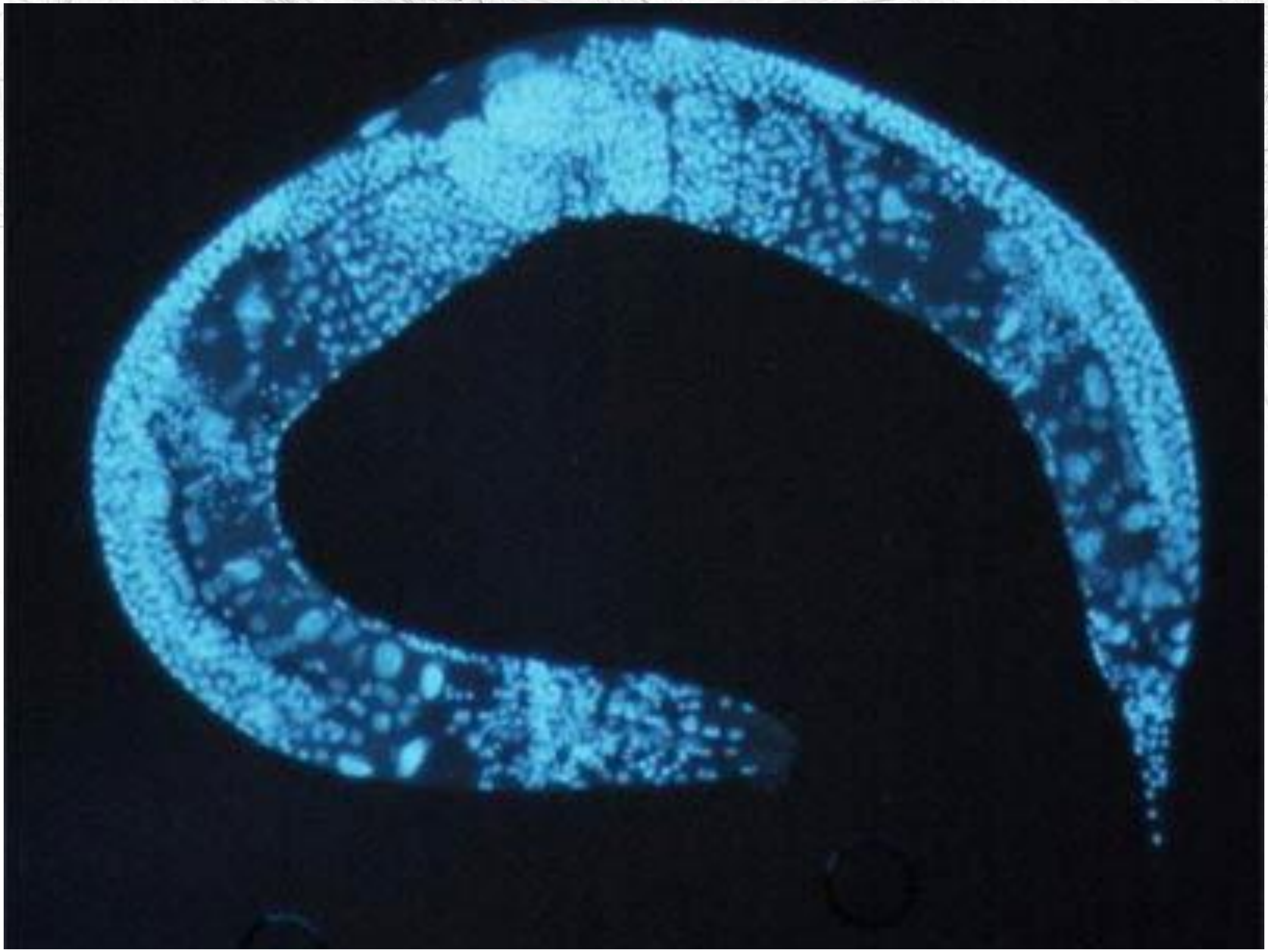








c. elegans



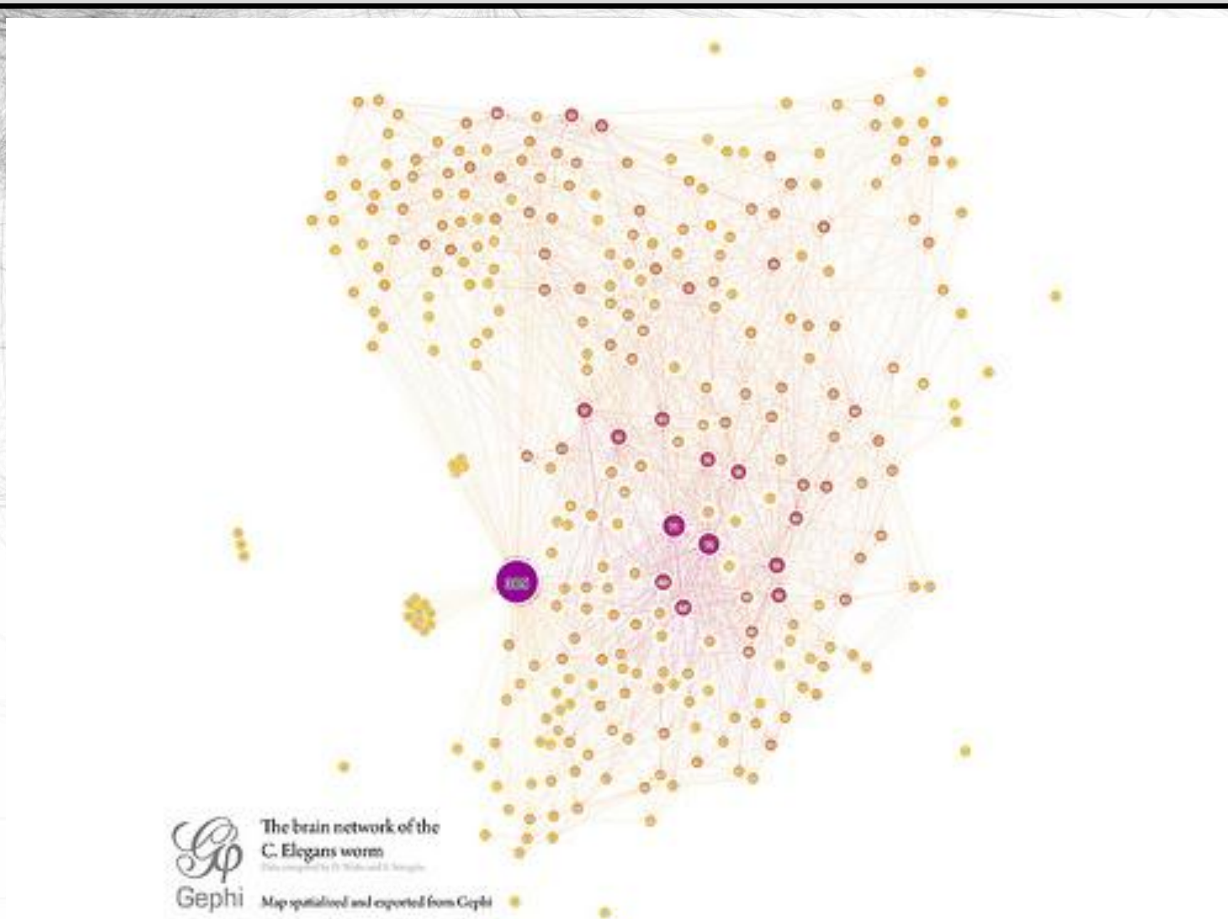
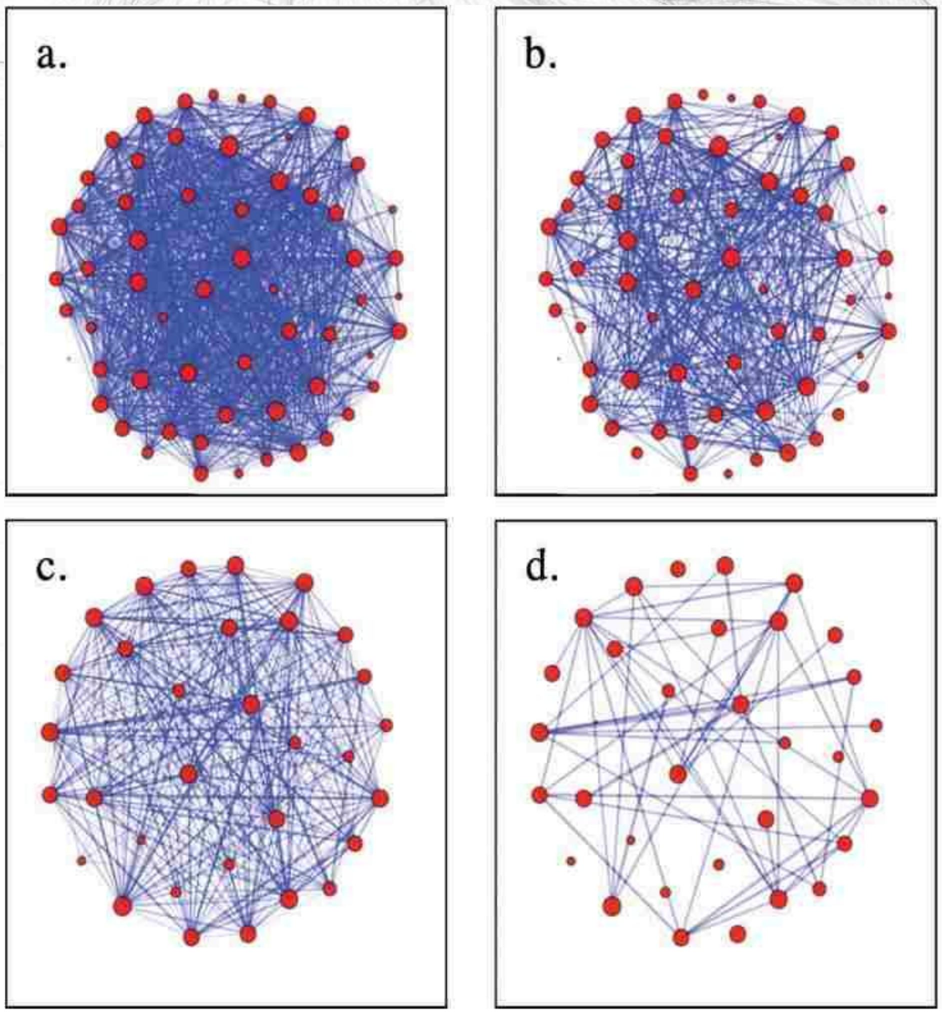


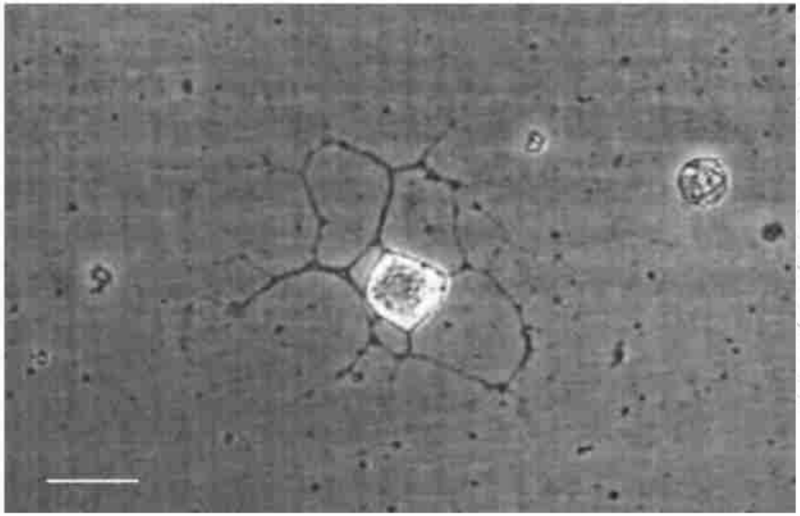
Table 1 Empirical examples of small-world networks

	L_{actual}	L_{random}	C_{actual}	C_{random}
Film actors	3.65	2.99	0.79	0.00027
Power grid	18.7	12.4	0.080	0.005
C. elegans	2.65	2.25	0.28	0.05

Watts & Strogatz (1998)

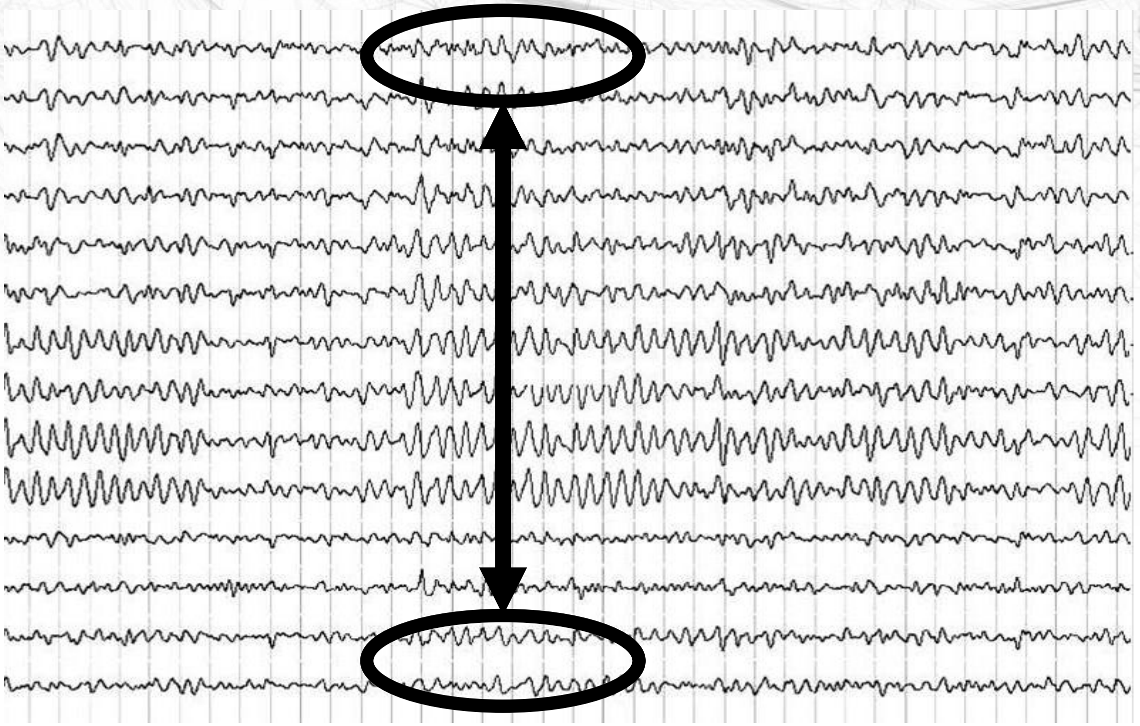
Neurons in vitro

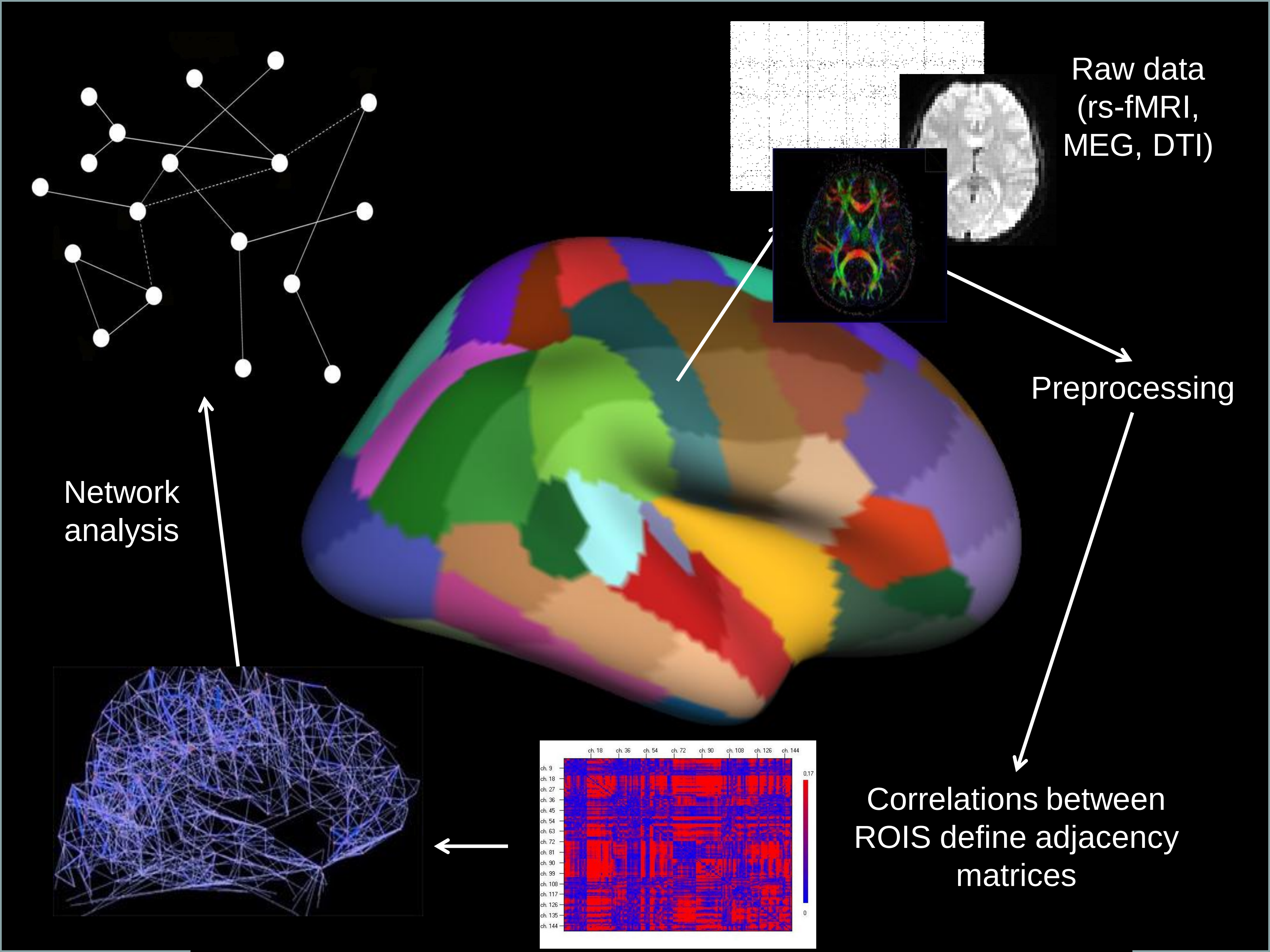


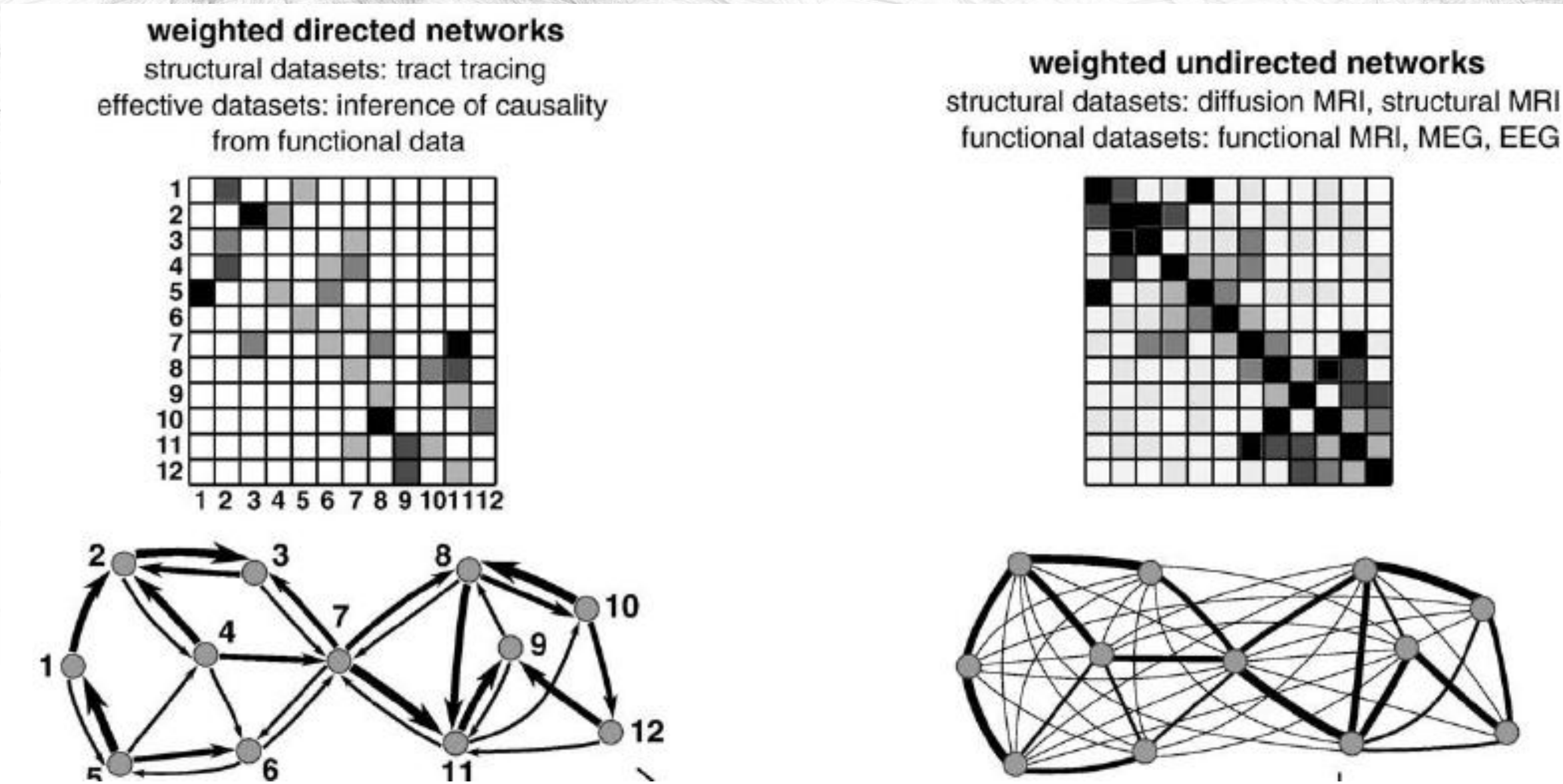


Bettencourt et al (2007), Shefi et al (2002)

EEG/MEG synchronization
fMRI correlation




Raw data
(rs-fMRI,
MEG, DTI)
Preprocessing
Correlations between
ROIS define adjacency
matrices
Network
analysis


weighted directed networks
structural datasets: tract tracing
effective datasets: inference of causality from functional data
weighted undirected networks
structural datasets: diffusion MRI, structural MRI
functional datasets: functional MRI, MEG, EEG

◆ Human Brain Mapping 22:97–109(2004) ◆

Scale-Free Dynamics of Global Functional Connectivity in the Human Brain

Cornelis Jan Stam[1]* and Eveline Astrid de Bruin[2]

PRL **110**, 108105 (2013) PHYSICAL REVIEW LETTERS week ending 8 MARCH 2013

Beyond Scale-Free Small-World Networks: Cortical Columns for Quick Brains

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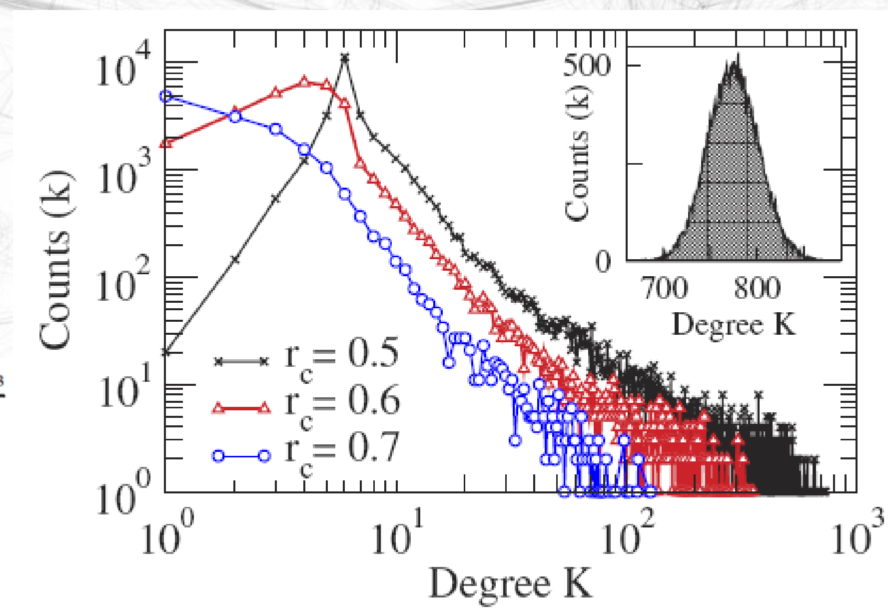
[3]*Institute of Forensic Medicine, University of Berne, 3012 Berne, Switzerland*
(Received 15 October 2012; published 7 March 2013)

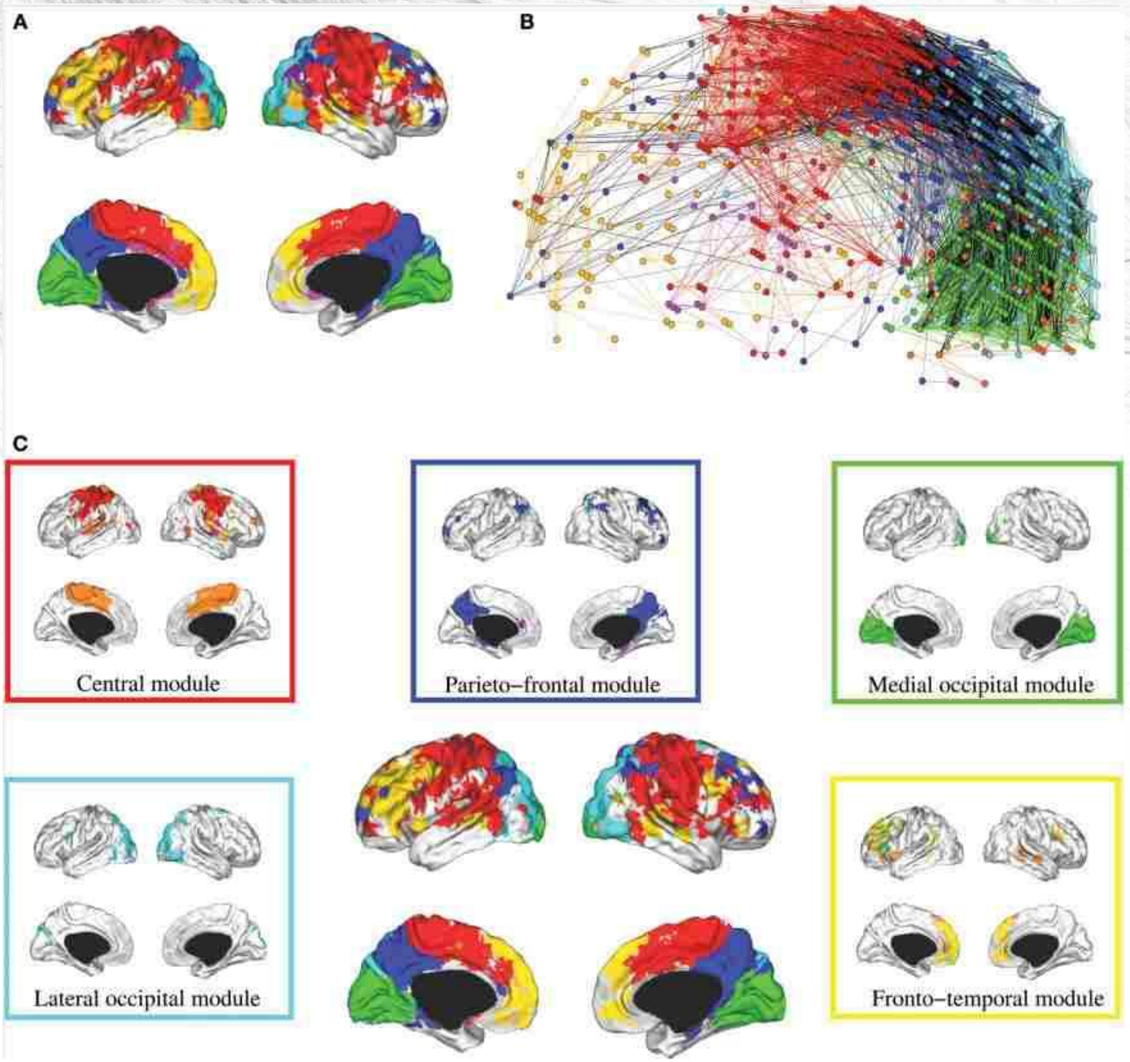
We study to what extent cortical columns with their particular wiring boost neural computation. Upon a vast survey of columnar networks performing various real-world cognitive tasks, we detect no signs of enhancement. It is on a mesoscopic—intercolumnar—scale that the existence of columns, largely irrespective of their inner organization, enhances the speed of information transfer and minimizes the total wiring length required to bind distributed columnar computations towards spatiotemporally coherent results. We suggest that brain efficiency may be related to a doubly fractal connectivity law, resulting in networks with efficiency properties beyond those by scale-free networks.

DOI: 10.1103/PhysRevLett.110.108105 PACS numbers: 87.19.L−, 05.65.+b, 89.75.Da, 89.75.Fb



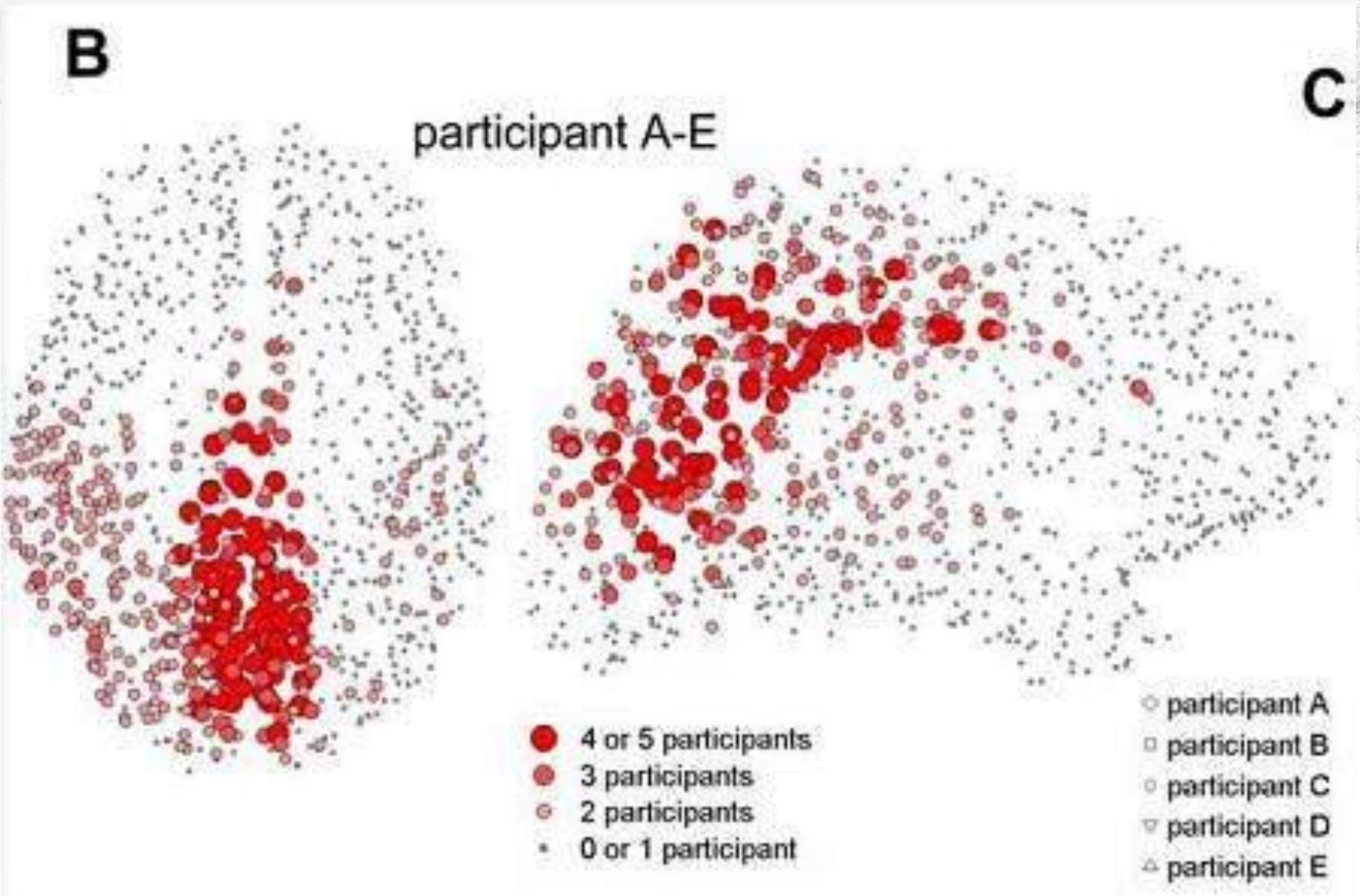
Achard et al (2006), Eguiluz et al (2005), Stam et al (2004), Stoop et al (2013)

Modules



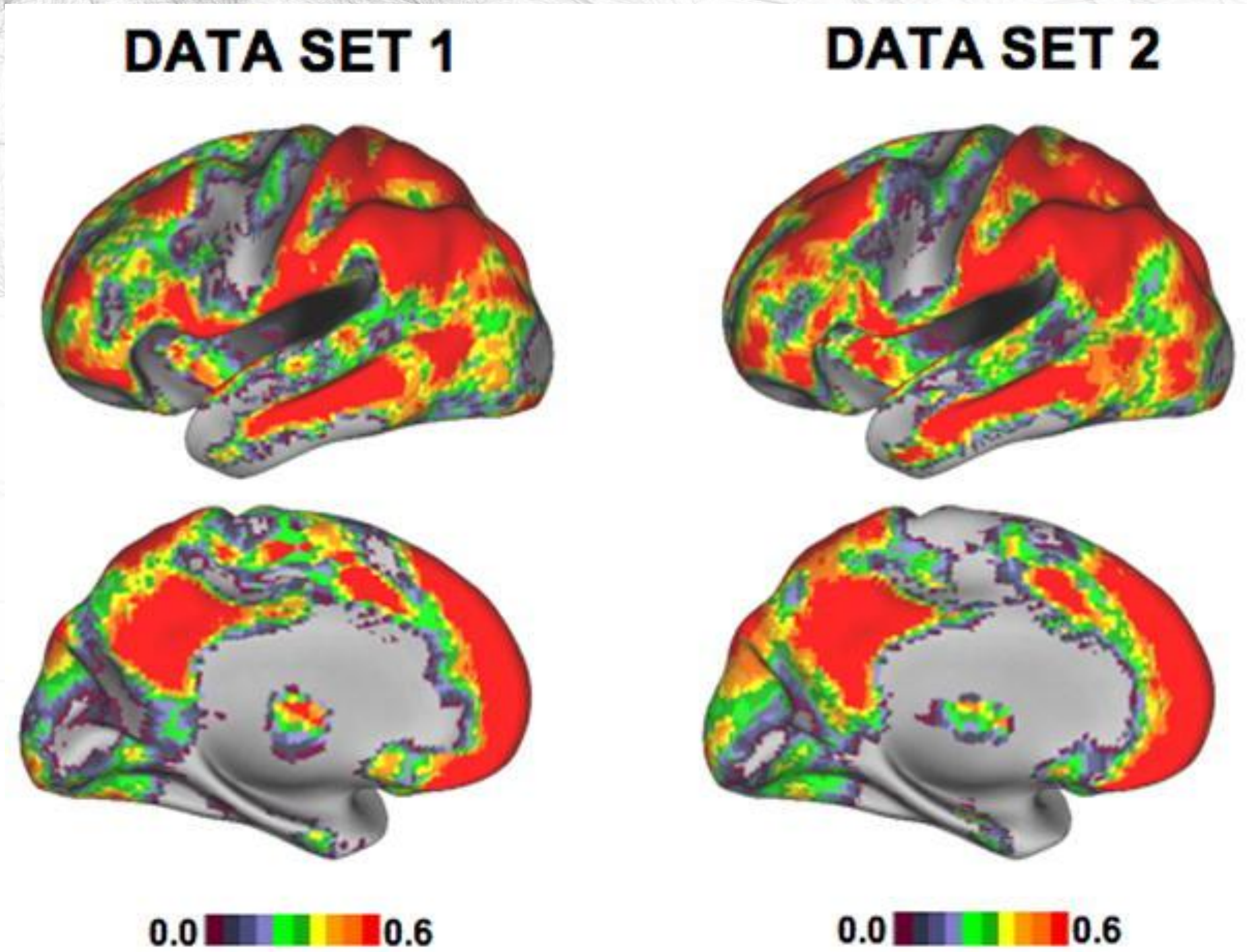
Meunier et al (2009)

Structural hubs



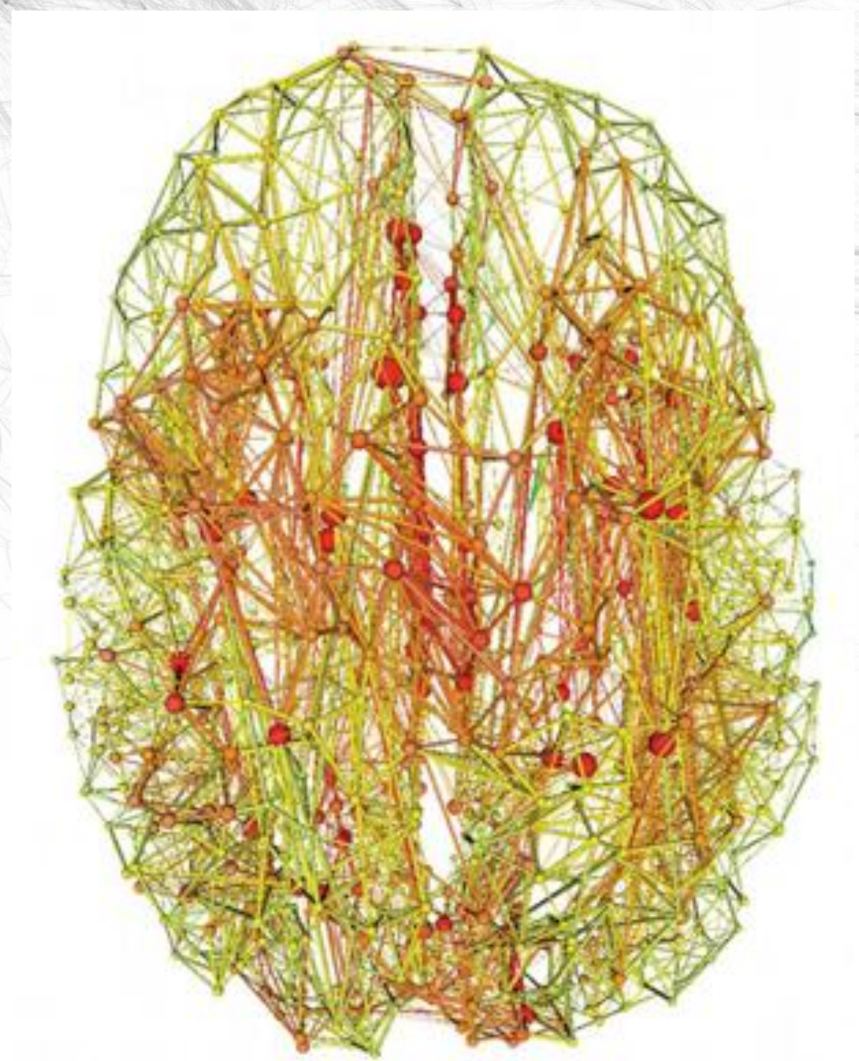
Hagmann et al (2008)

Functional hubs



Buckner et al (2009)

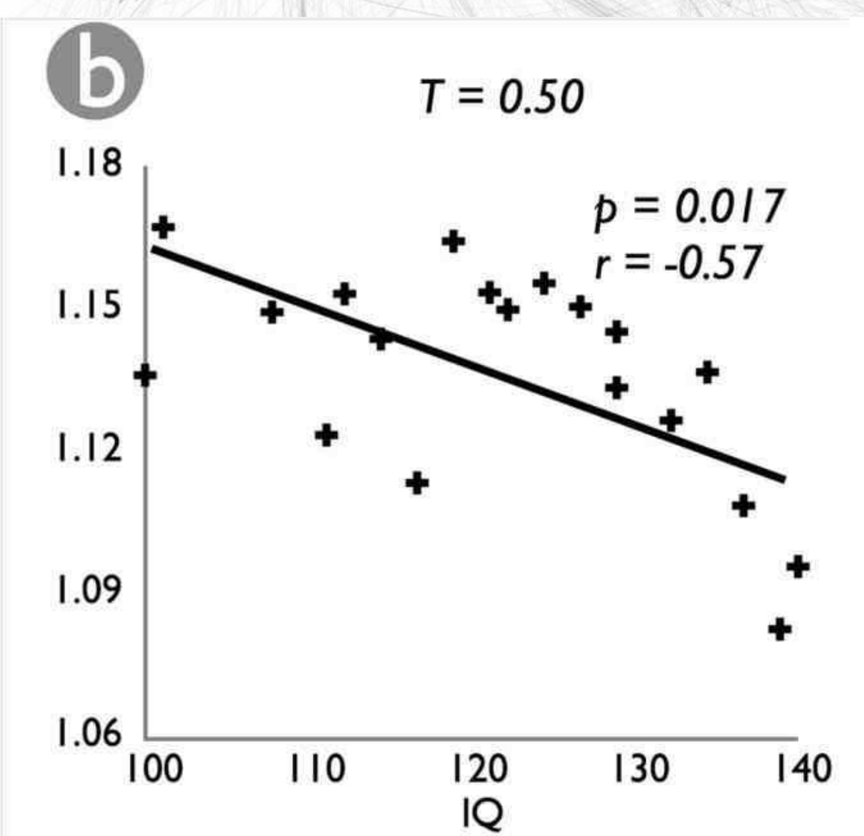
Rich-club



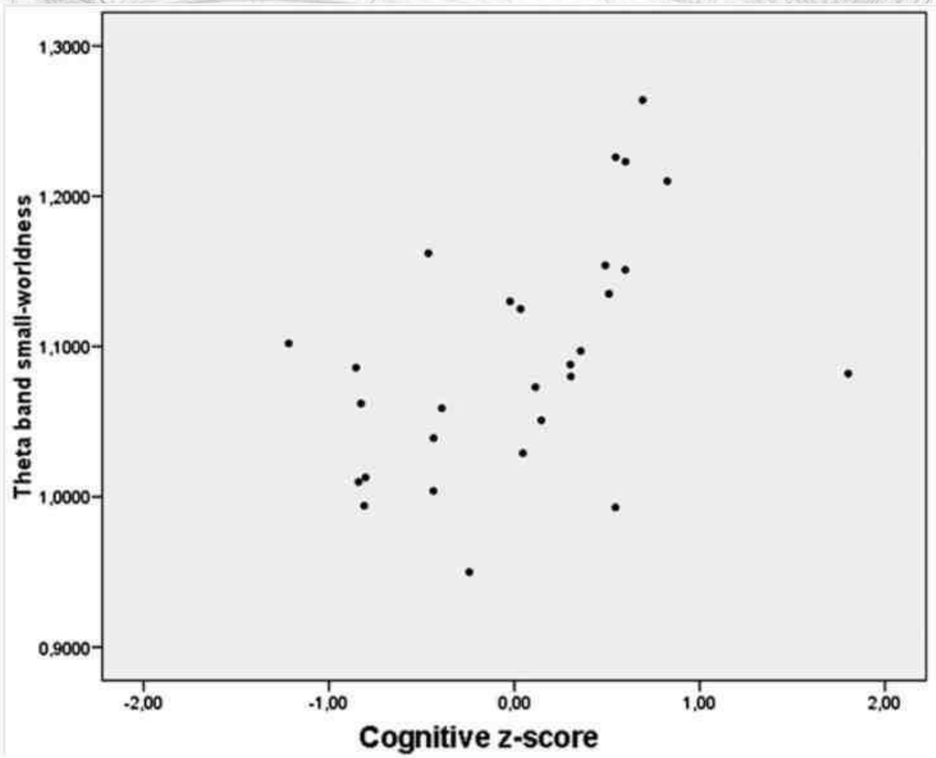
Van den Heuvel & Sporns (2011)

Cognition

Efficiency



Small-worldness

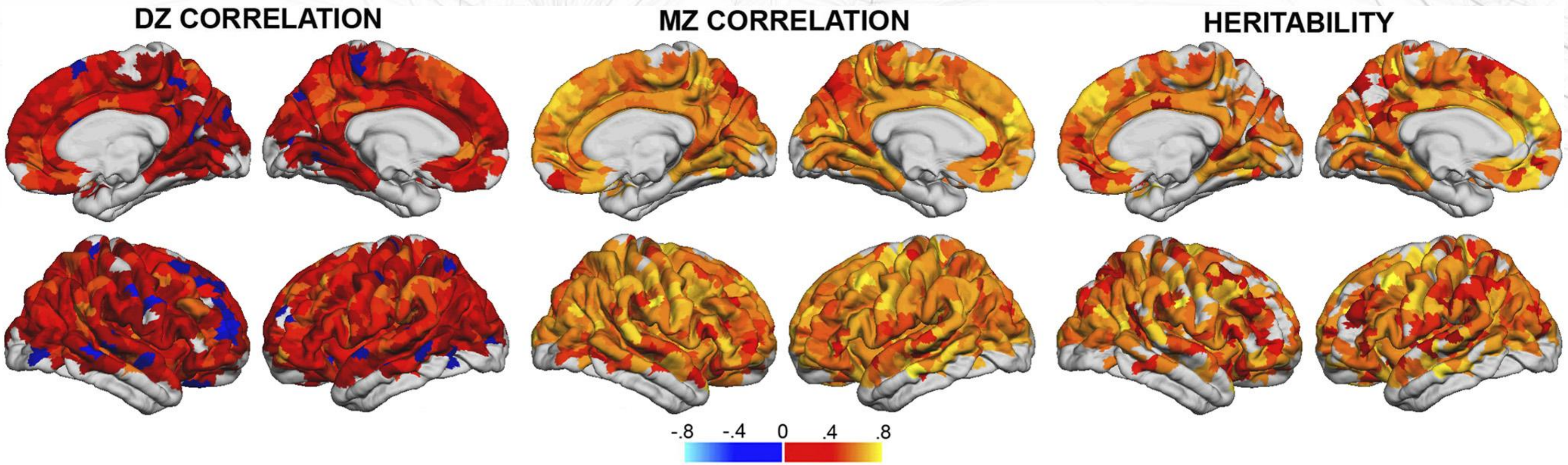


Van den Heuvel et al (2009) J Neurosci; Douw et al (2011) Neurosci

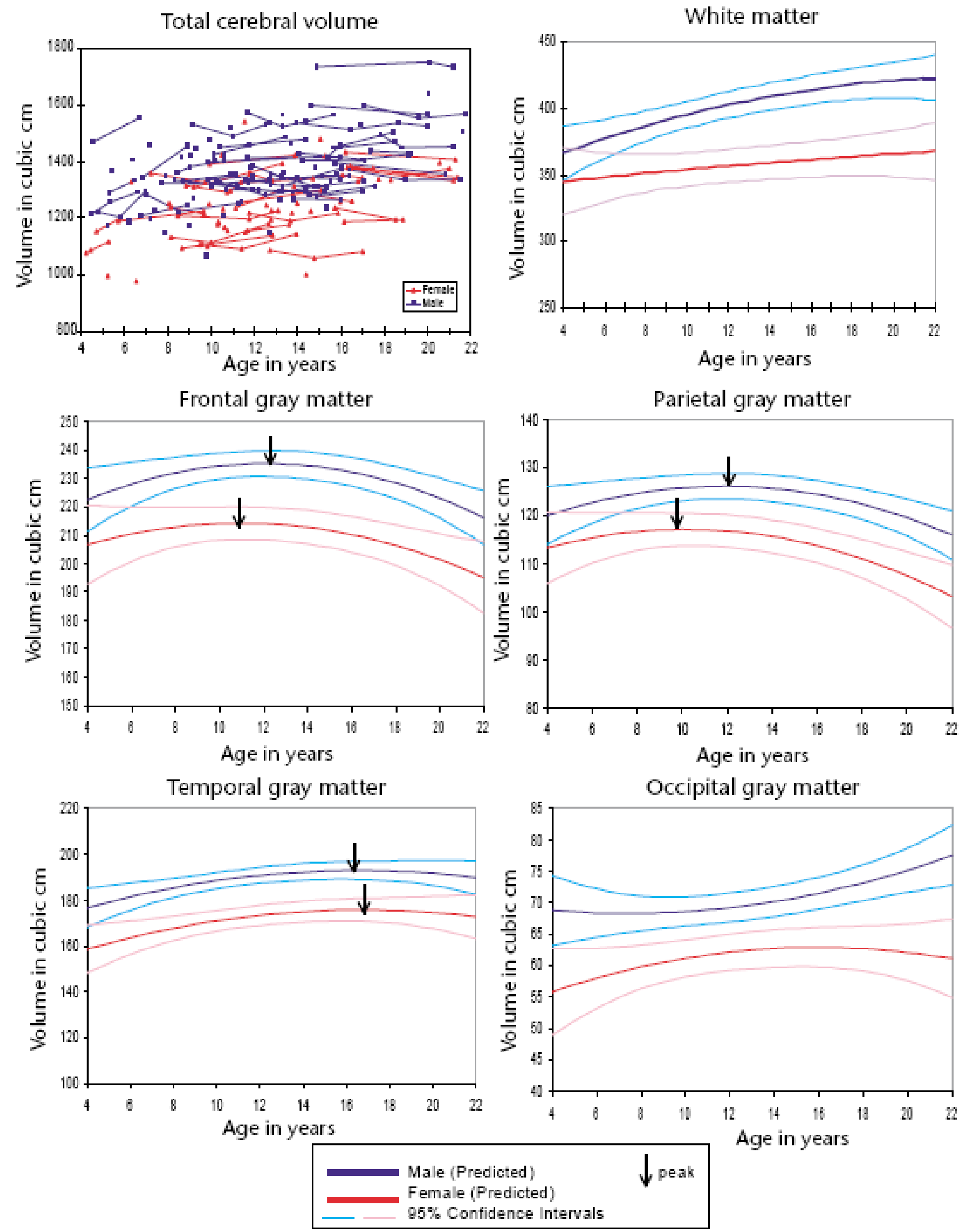
Genetics component

TABLE VI. Heritabilities for C, L, and σ

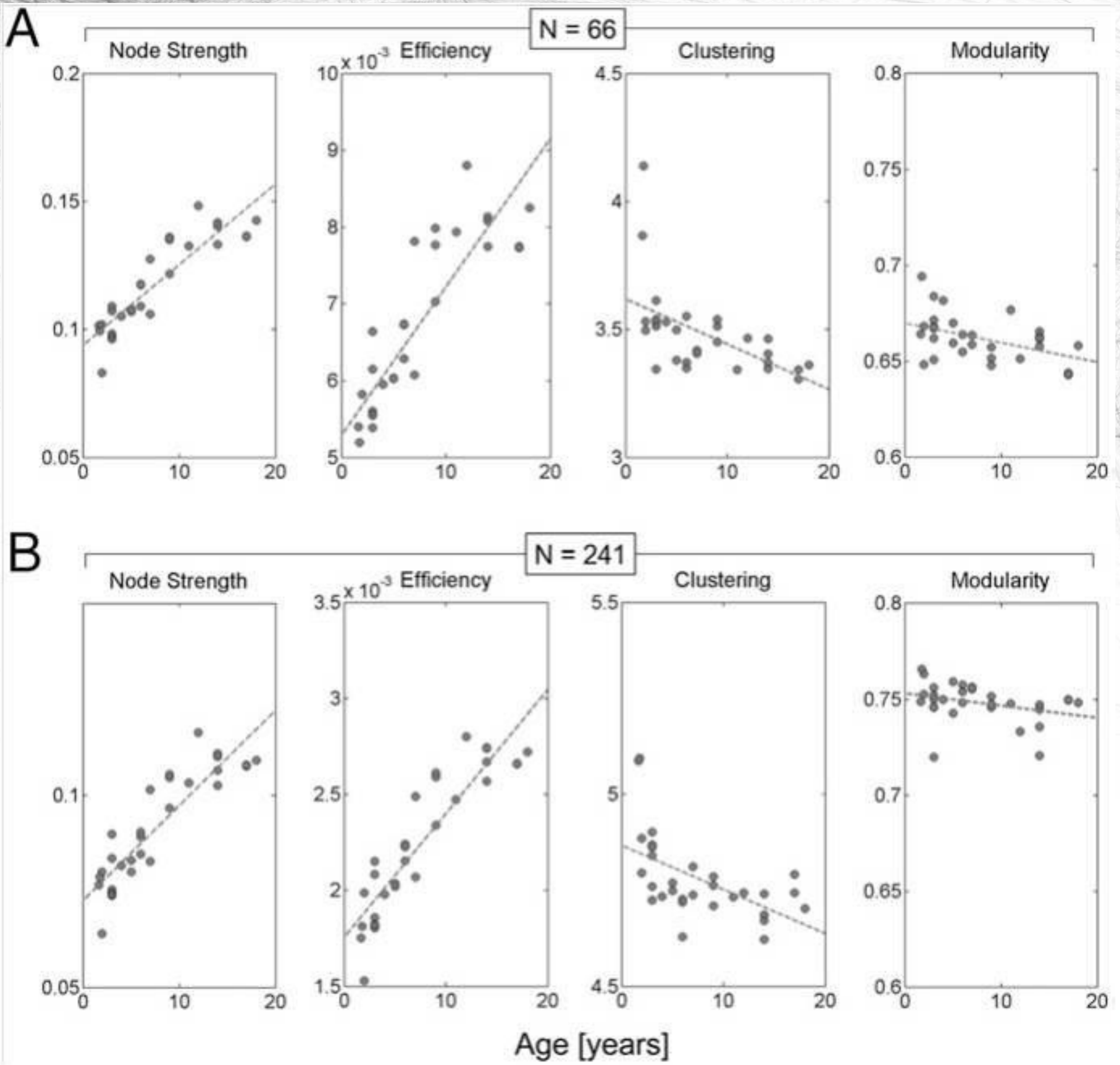
	C		*L*		σ
Theta	0.50	*	0.89	*	0.37
Lower alpha	0.37		0.46	***	0.51
Upper alpha	0.39		0.78	***	0.00
Lower beta	0.62	**	0.53	***	0.27
Upper beta	0.54	***	0.70	***	0.39



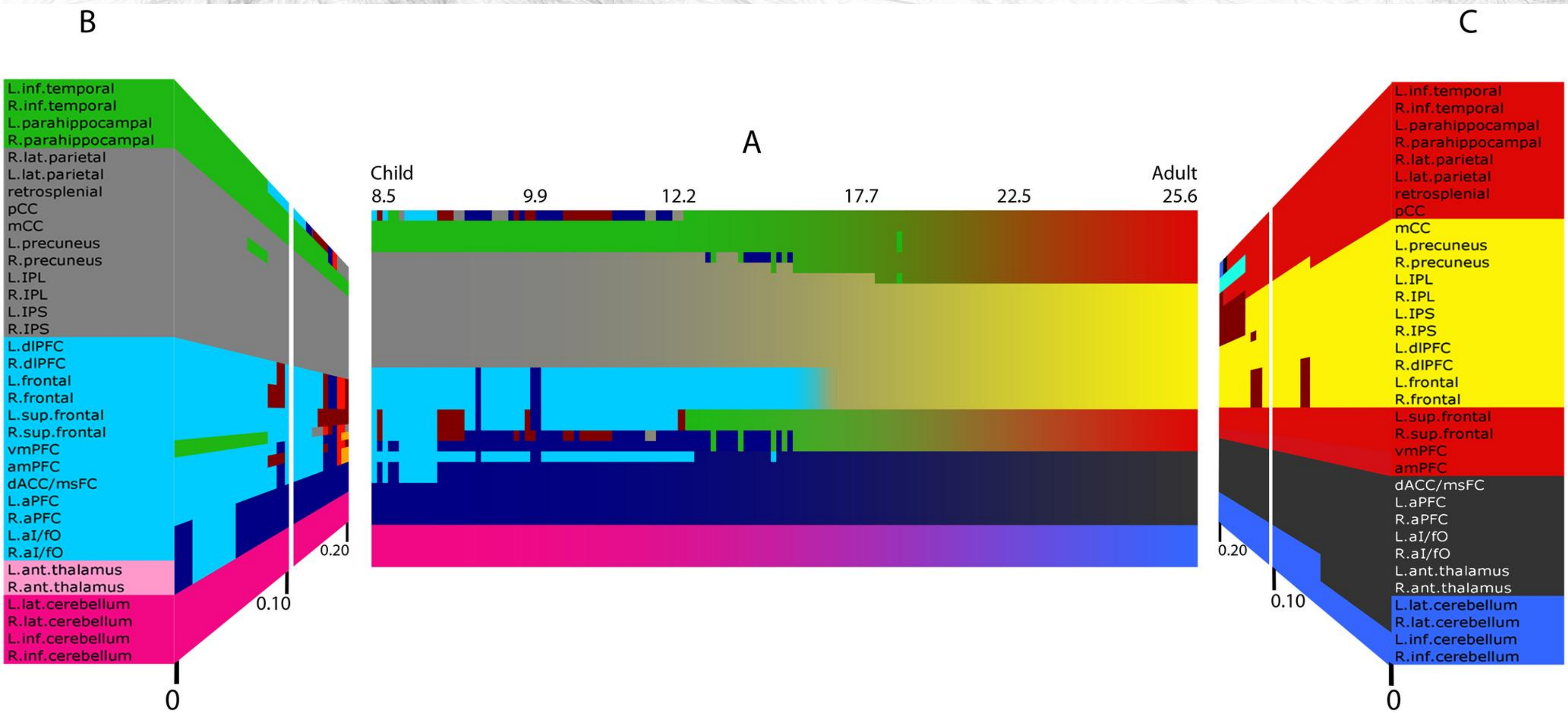
Smit et al (2008), Fornito et al (2011)



Giedd et al (1999)



Hagmann et al (2010)

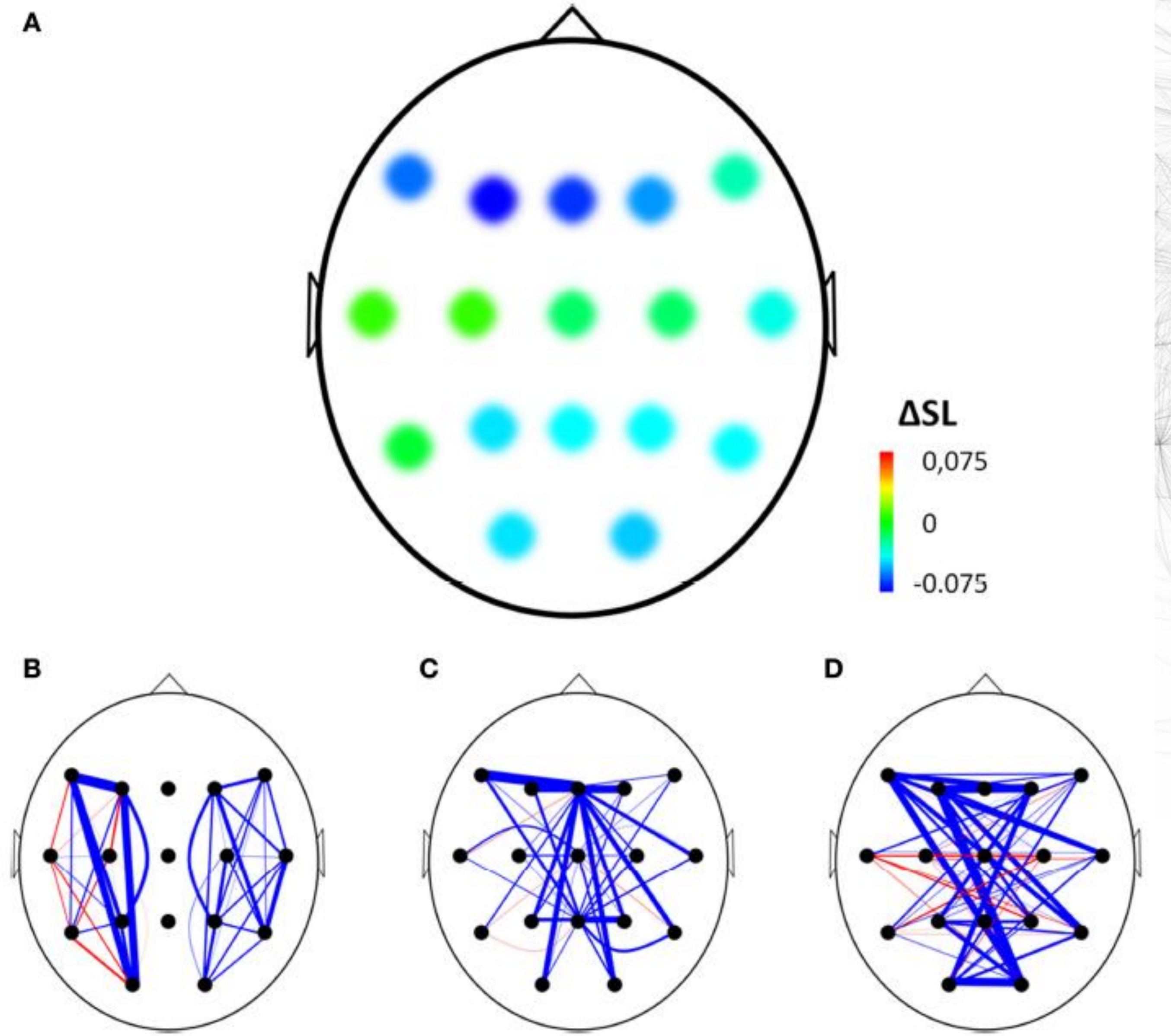


Fair et al (2009)

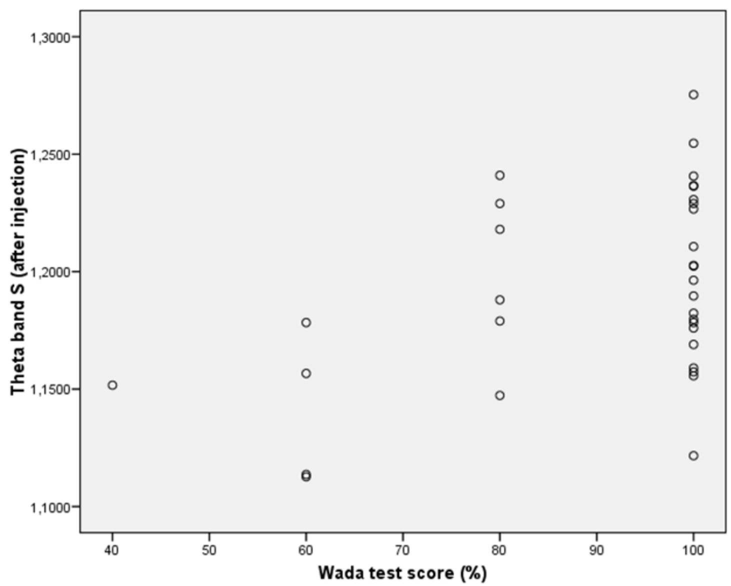
More immediate dynamics

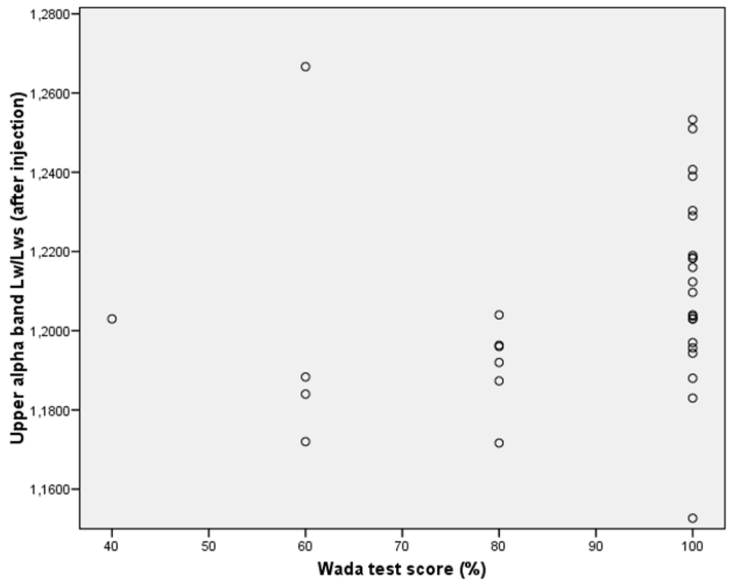
- Wada test:
  - Unilateral intracarotid injection of sodium amobarbital
  - Preoperative procedure of epilepsy surgery
  - To determine lateralization of language and memory
  - 21-channel EEG recording
- Analyzed 30s before and directly after injection

Douw et al (2009) NeuroImage; Douw et al (2010) Front Hum Neurosci



Douw et al (2009) NeuroImage; Douw et al (2010) Front Hum Neurosci

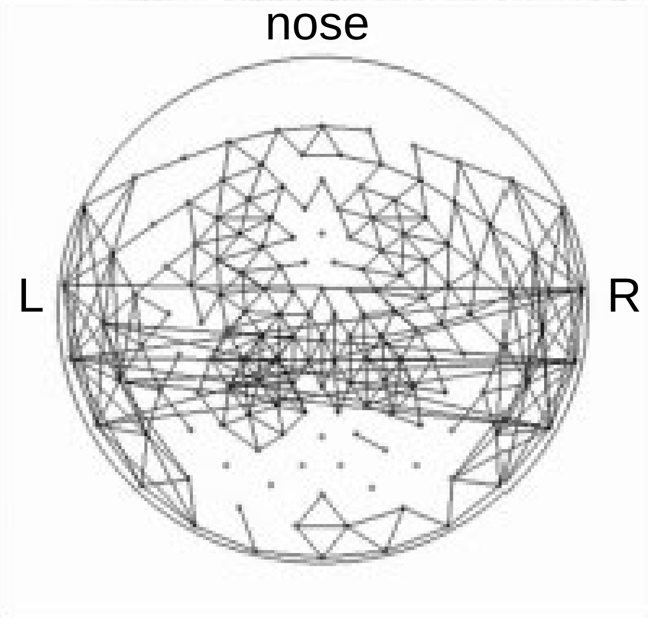


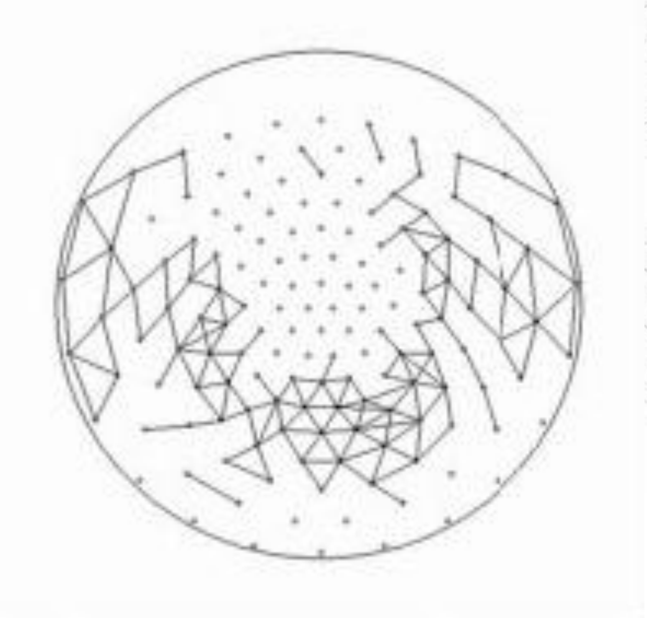


Douw et al (2009) NeuroImage; Douw et al (2010) Front Hum Neurosci

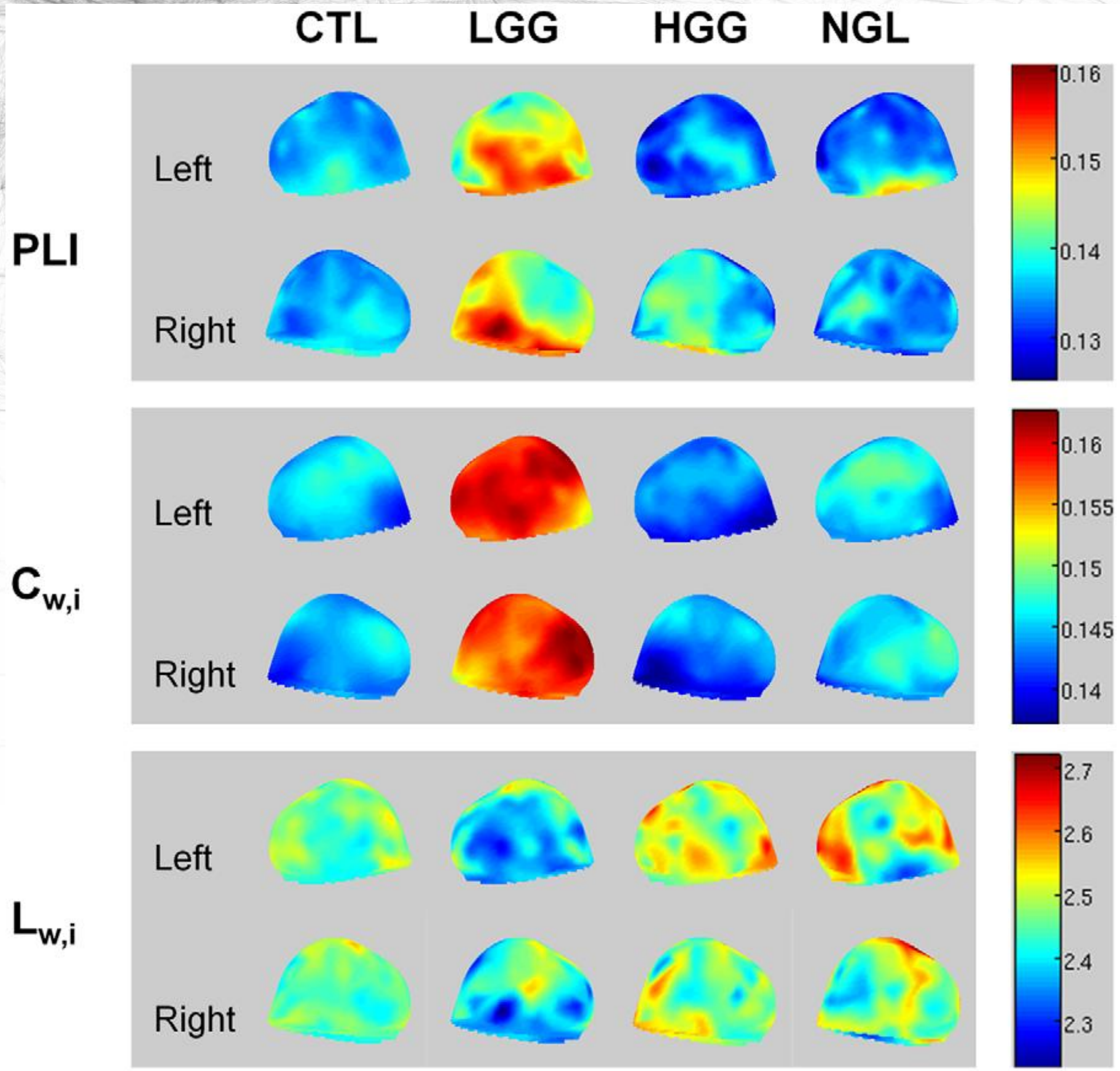
Brain tumors

Healthy control Patient MRI Patient

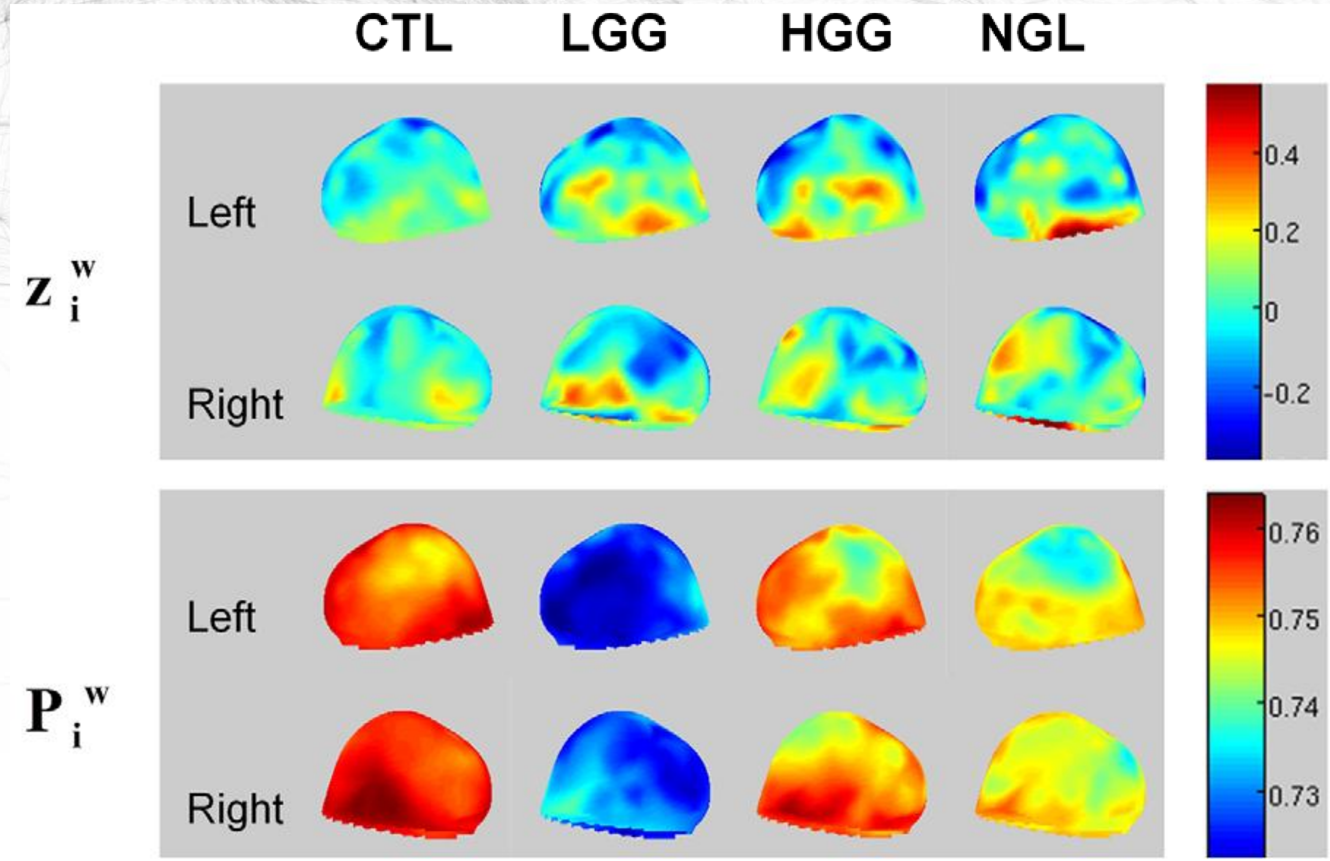




Bartolomei (2006) Clin Neurophysiol

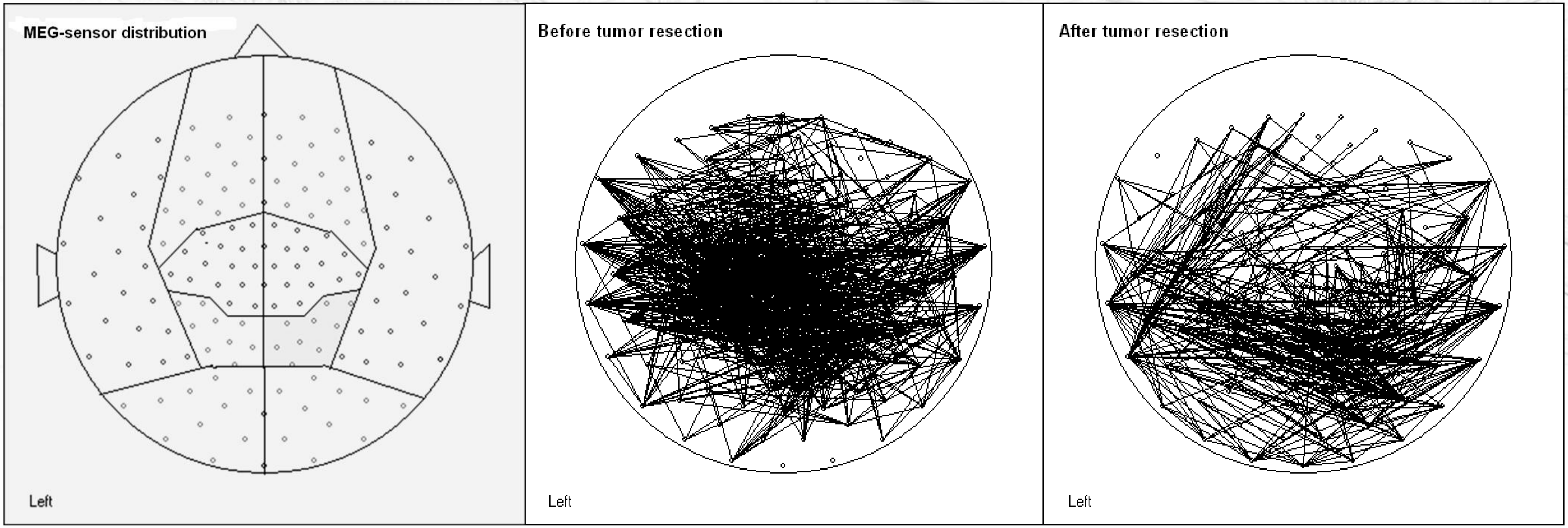


Van Dellen et al (2012)

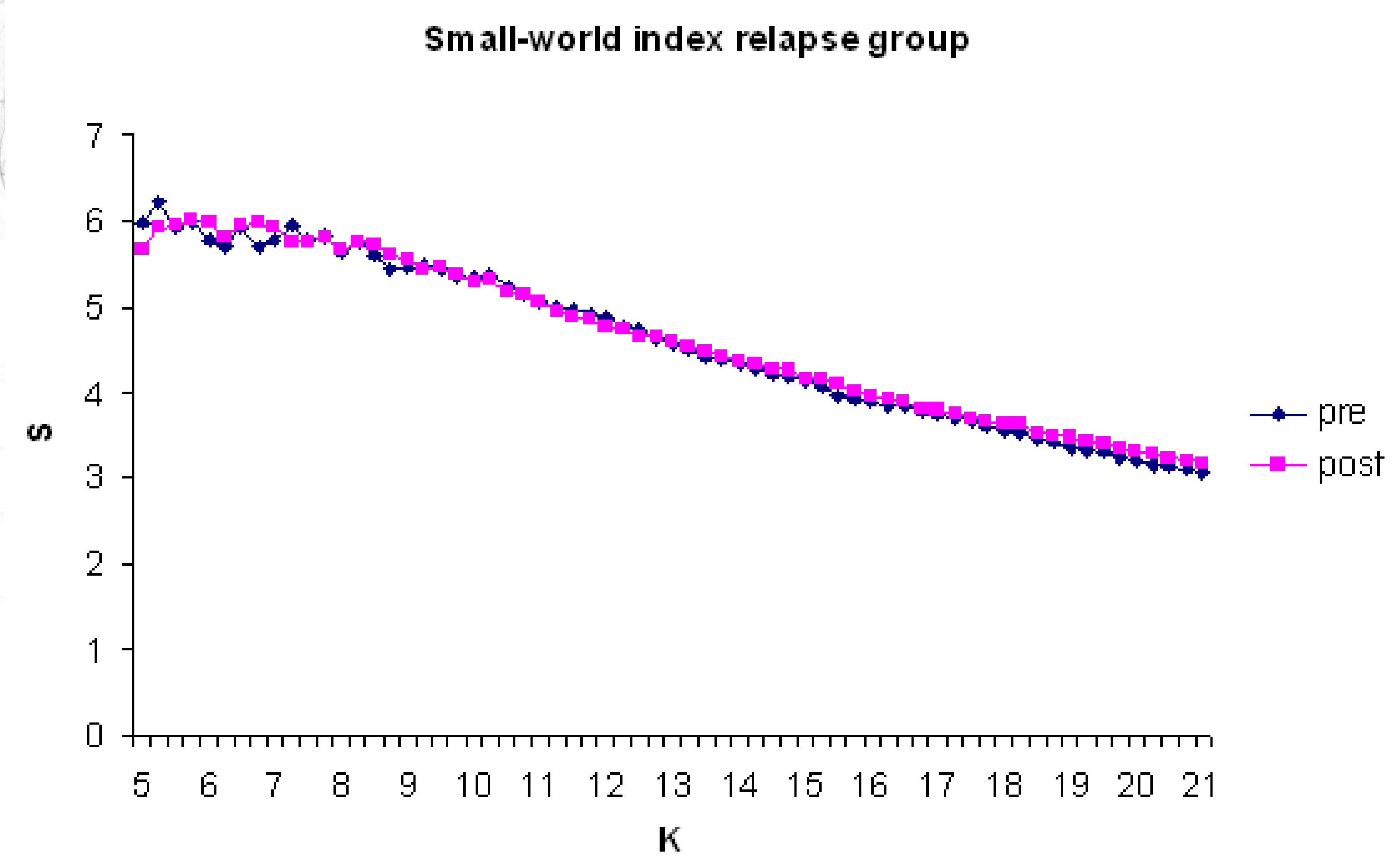


Van Dellen et al (2012)

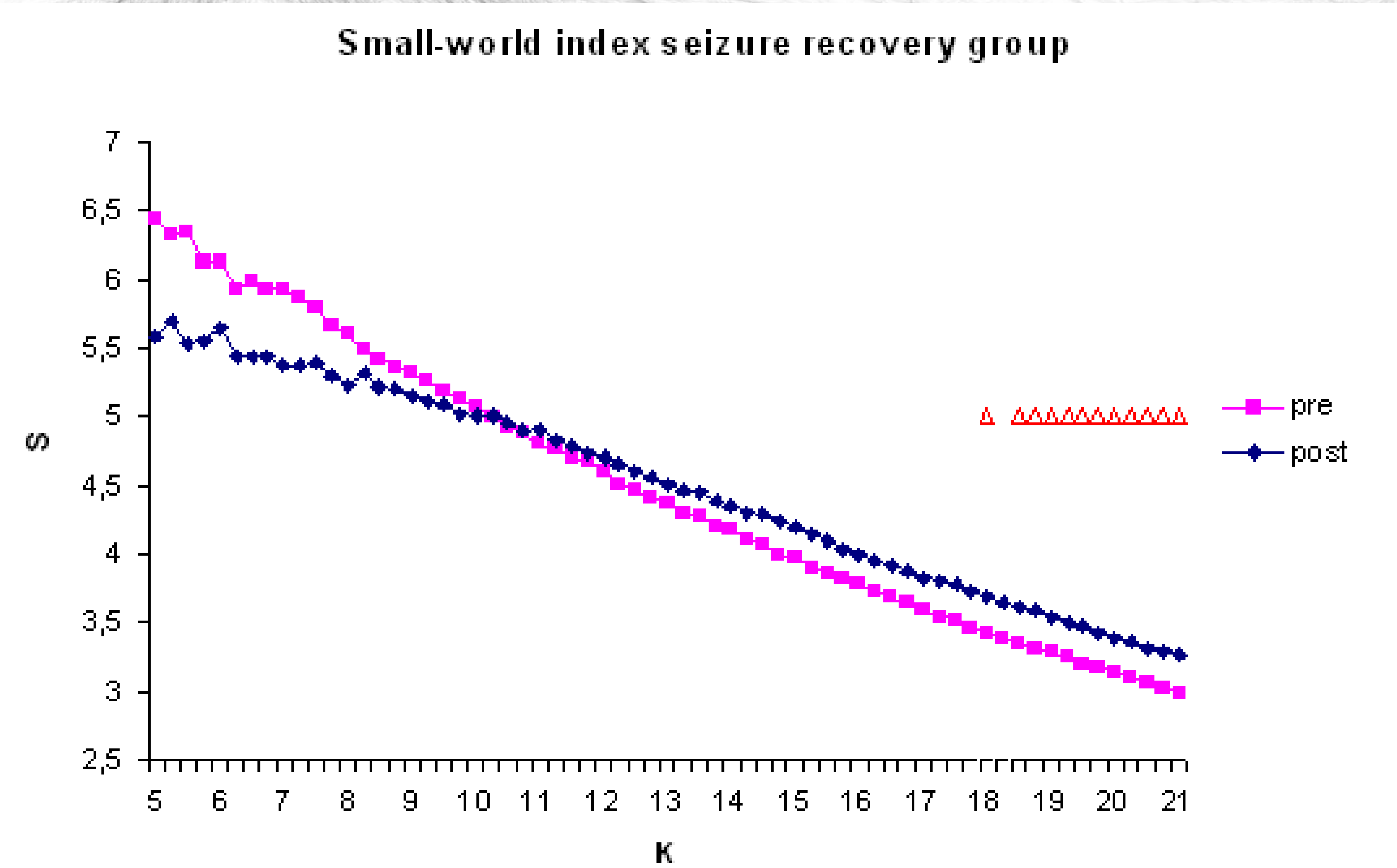
Tumor resection



Douw et al (2008) Exp Neurol

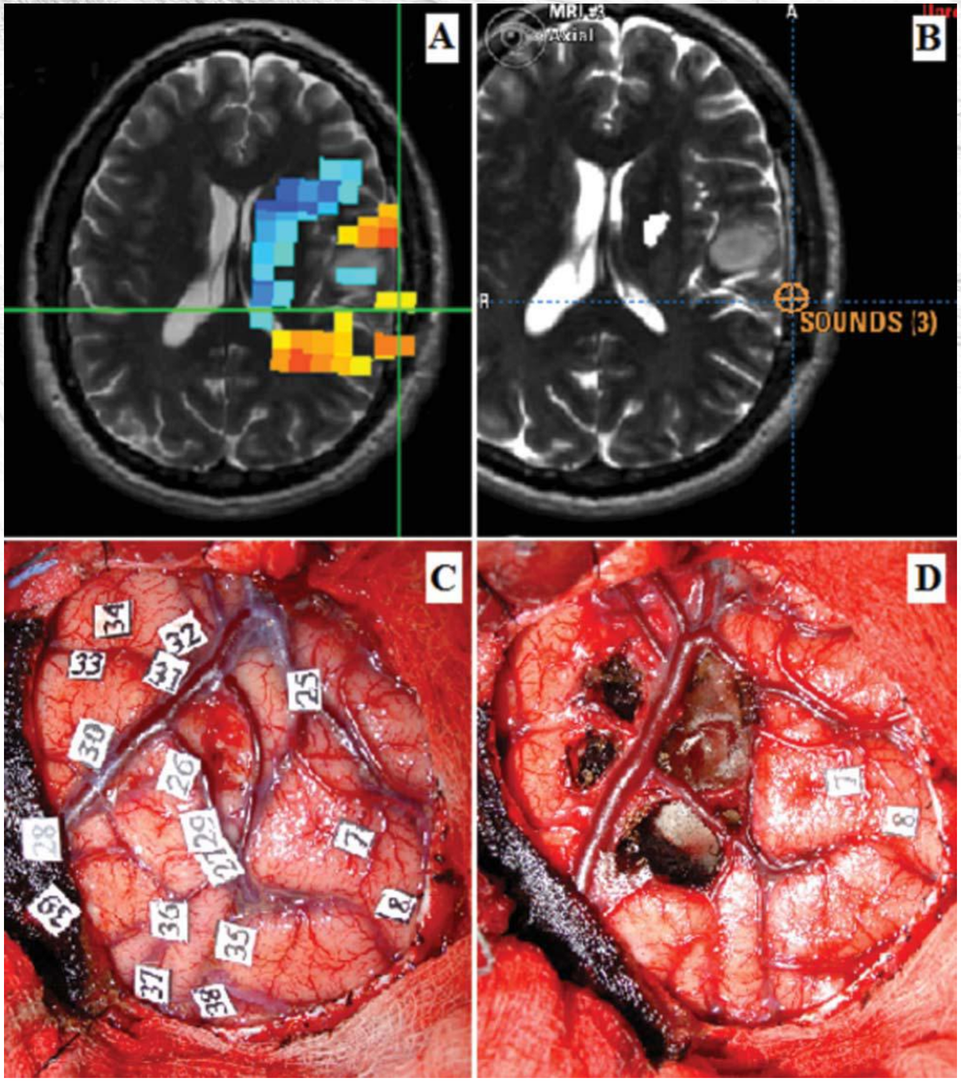


Douw et al, unpublished data



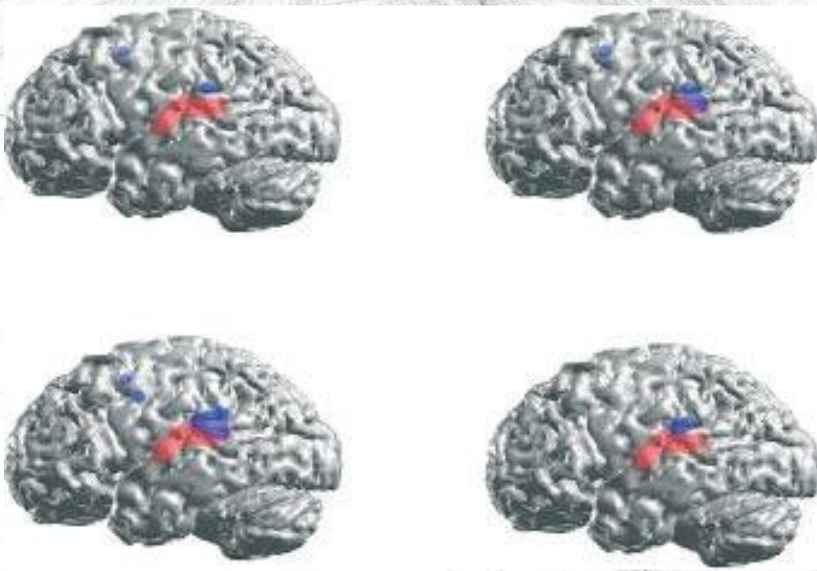
Douw et al, unpublished data

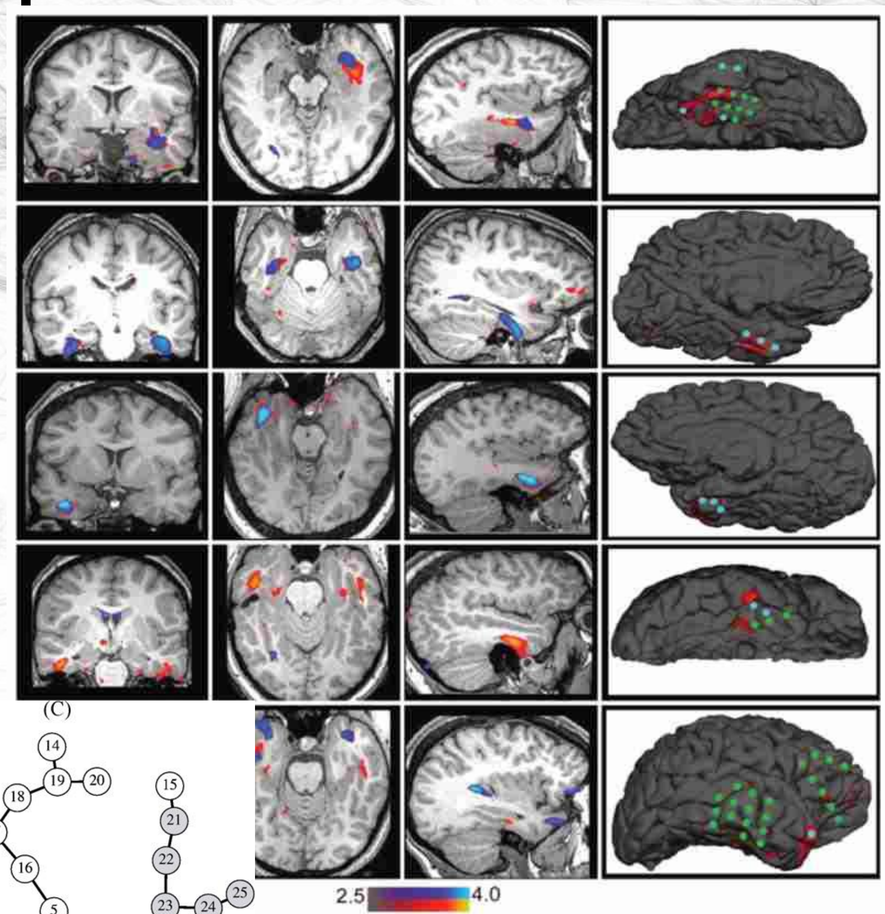
Clinical applications

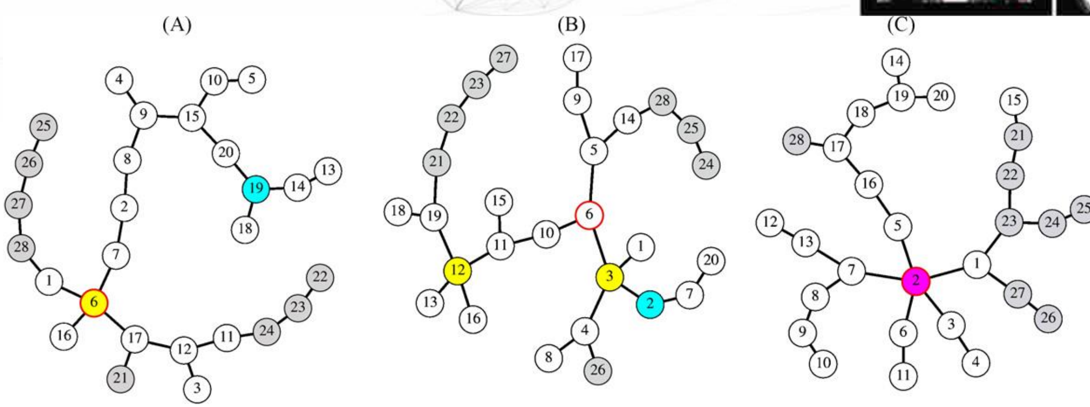


Martino et al (2011), Taragone et al (2012)

Clinical applications

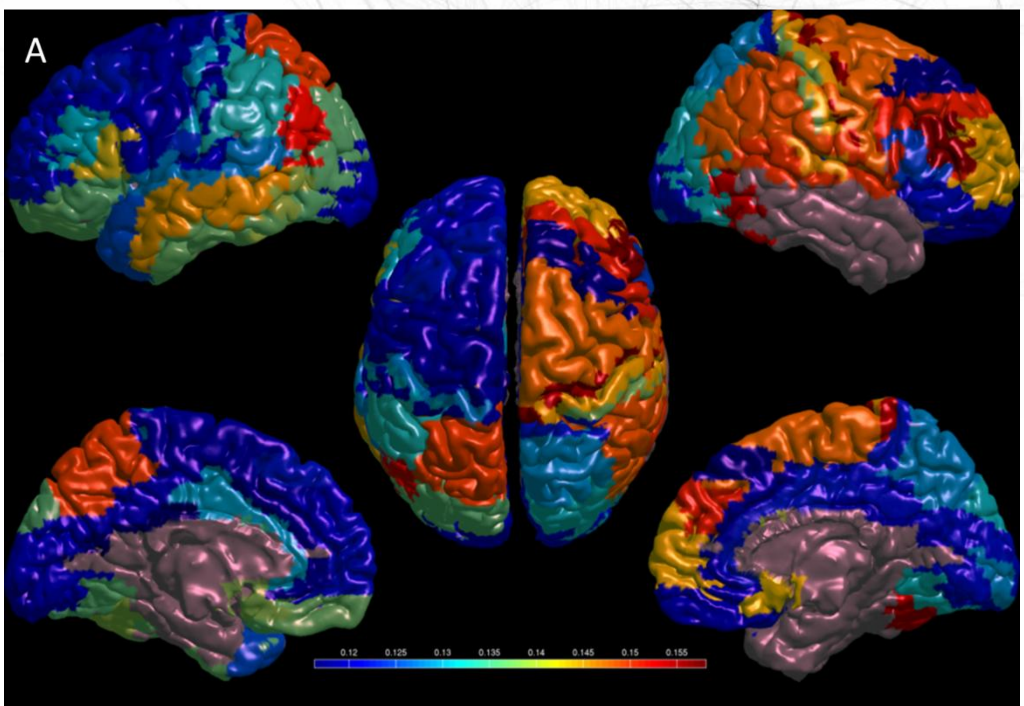


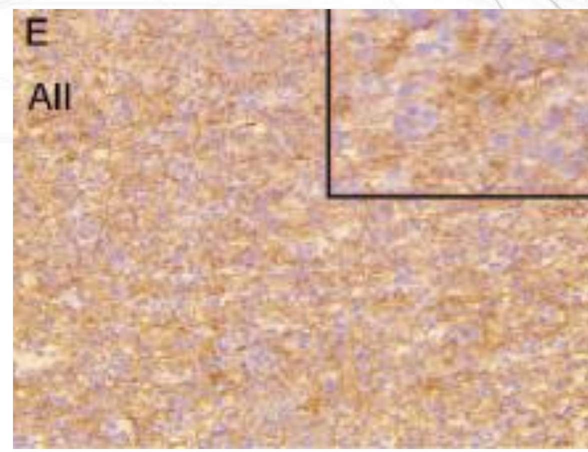




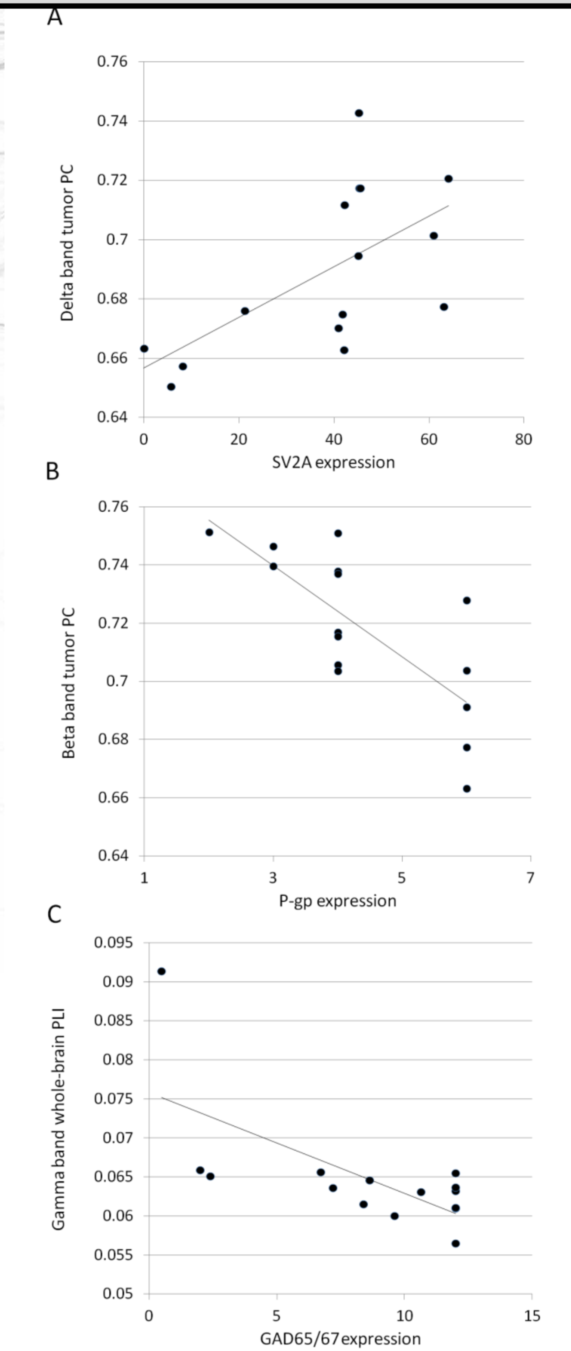
Ortega et al (2008), Stufflebeam et al (2011), Wilke et al (2011)

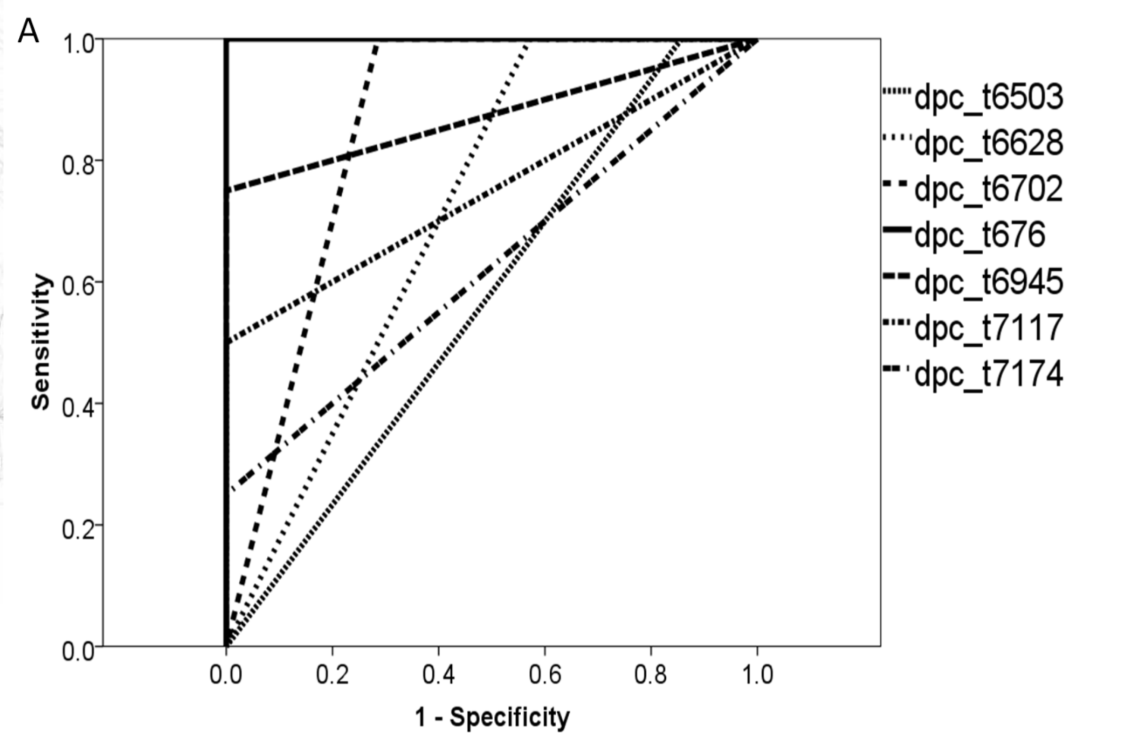
Large-scale network topology: the intermediate between cells and behavior?





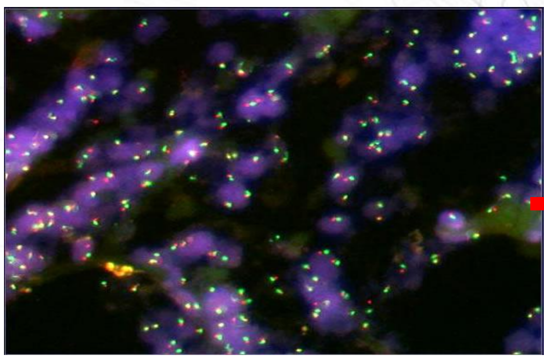
Douw et al (2013)

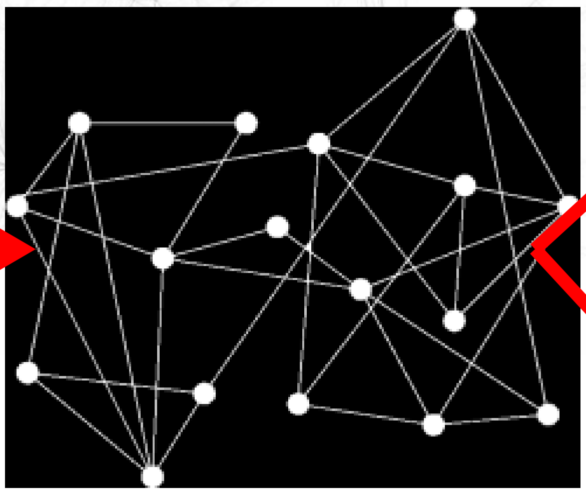


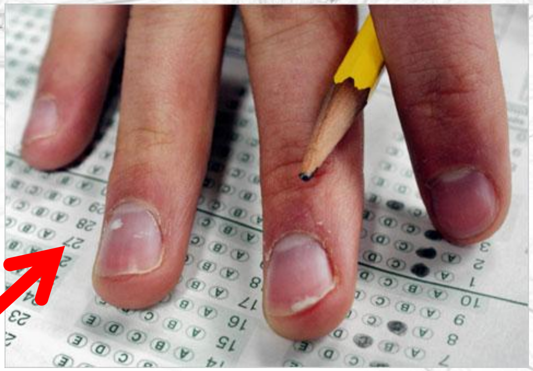


Douw et al (2013)

Network topology: the intermediate between cells and behavior?







It's a small (world) brain after all!

"How Kevin Bacon cured cancer", documentary featuring Strogatz & Barabasi
http://www.youtube.com/playlist?list=PL2DB408AF84F66CD9

TED talk by Strogatz on synchronization in complex systems
http://www.ted.com/talks/steven_strogatz_on_sync.html