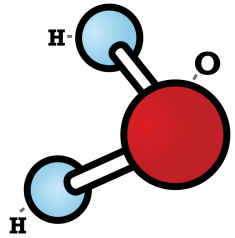
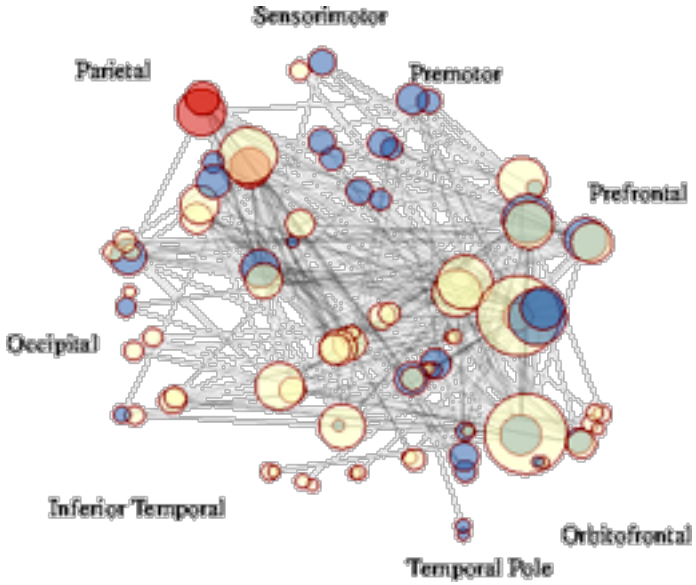
Graph analysis of functional brain networks: theory, applications and issues

Fabrizio DE VICO FALLANI

INRIA Paris-Rocquencourt – ARAMIS team
Institut du Cerveau et de la Moelle épinière (ICM)
Paris, France

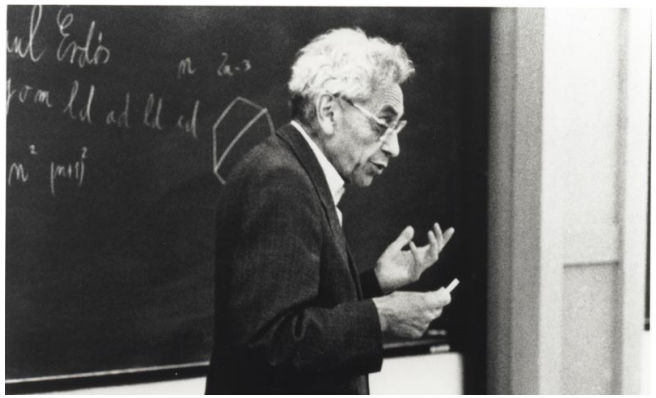
Emergence in connected systems



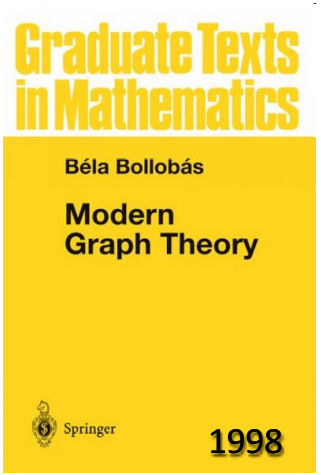


Varela et al, Nat Neurosci, 1999

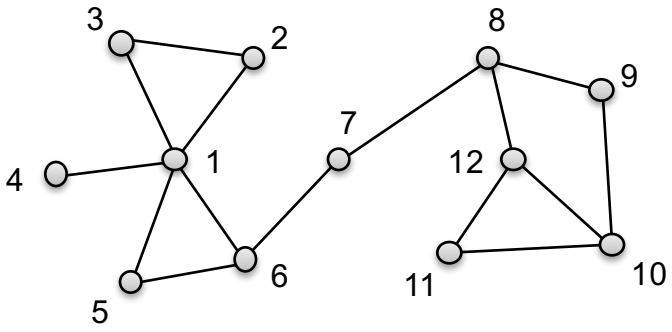
A graph theoretical approach



Paul Erdos (1913-1996)

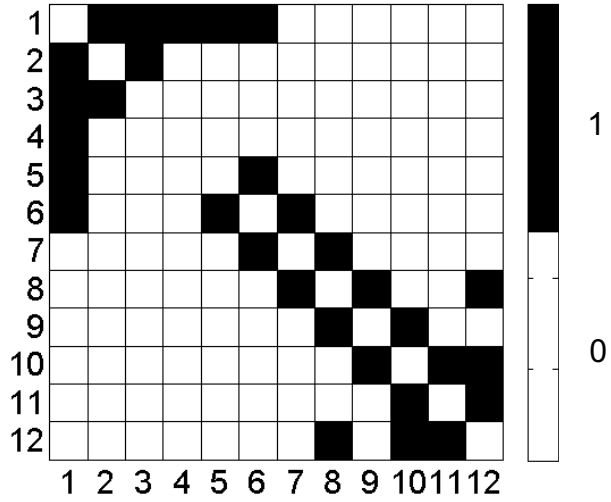


Graph G

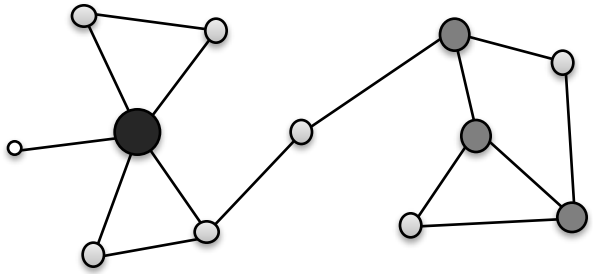


N=12

$$\mathbf{A} = \{a_{i,j}\} =$$

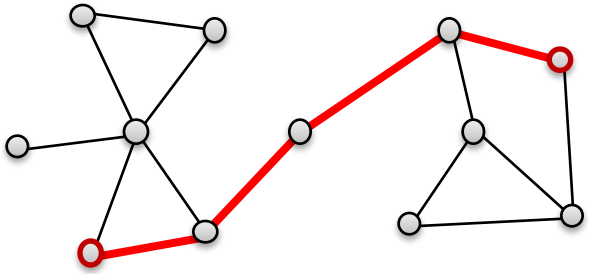


Quantifying network properties



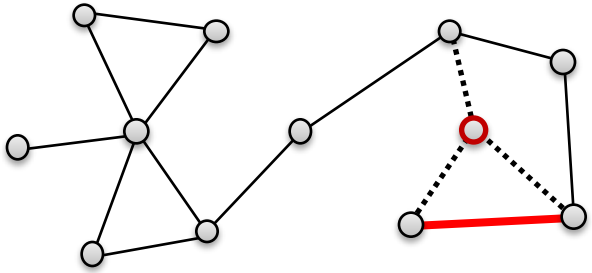
Node degree

$$k(i) = \sum_{j=1}^{N} a_{i,j}$$



Global efficiency (1/distance)

$$E_{\text{glo}} = \frac{1}{N(N-1)} \sum_{i,j=1}^{N} 1/d_{i,j}$$

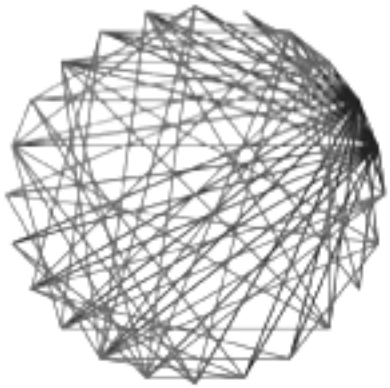


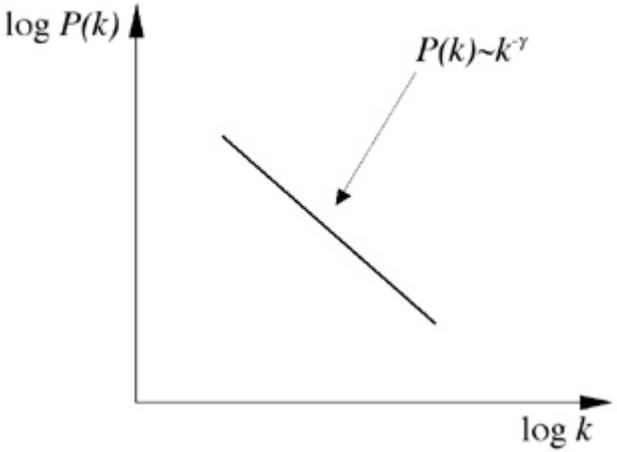
Clustering (Local efficiency)

$$E_{loc} = \frac{1}{N} \sum_{i=1}^{N} E_{glob}(i)$$

Universal properties of complex networks

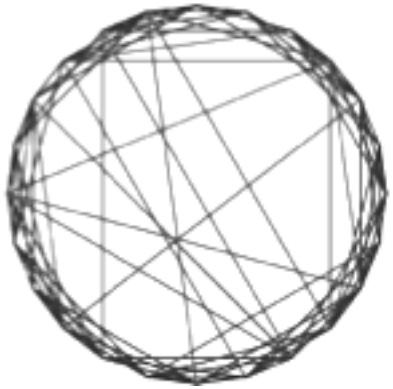
Scale-free

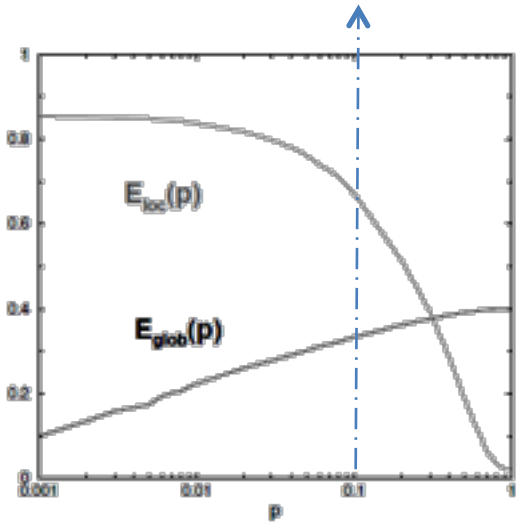




Barabasi & Albert, Nature, 2001

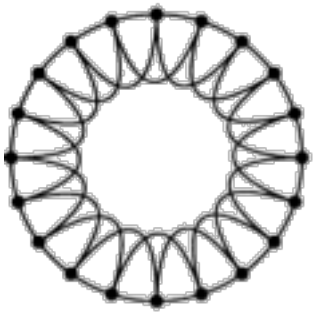
Small-world



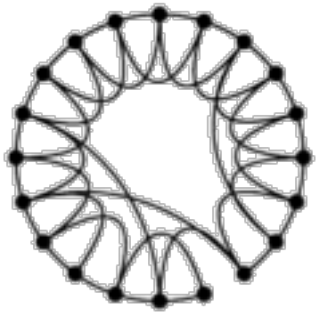


Watts & Strogatz, Science, 1998

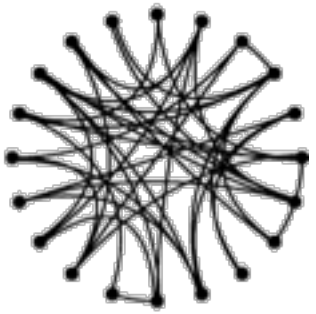
Small-world brain networks



Regular



Small-world

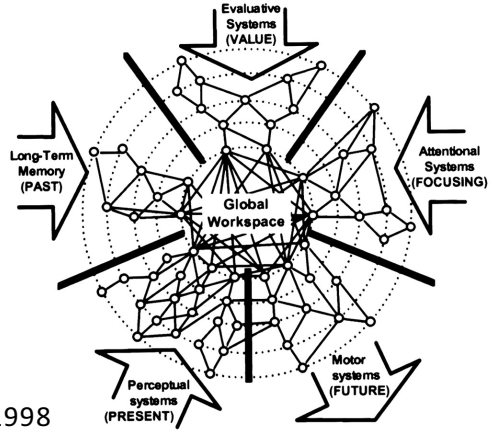


Random

« Phrenology »

Segregation

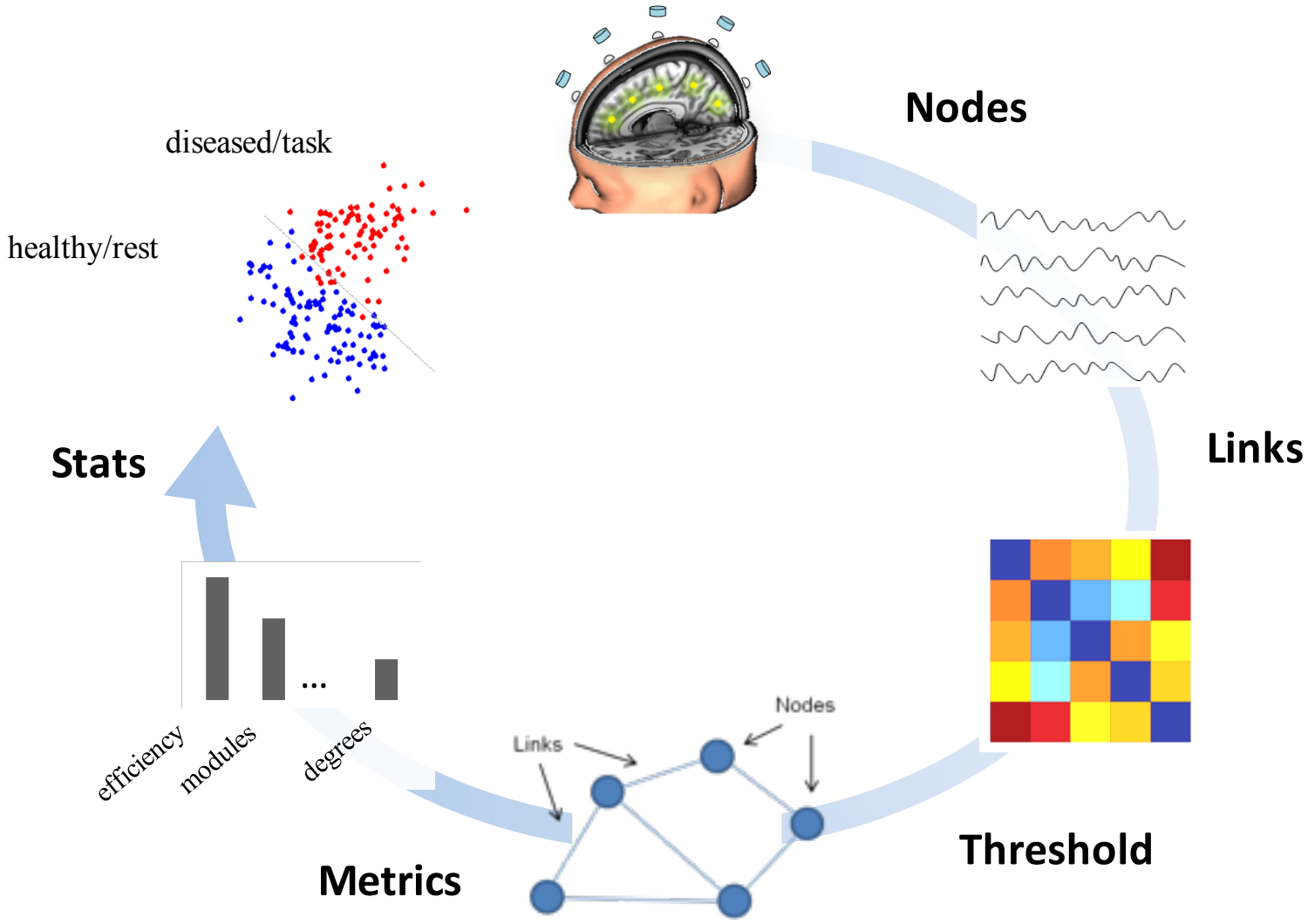
Dahene et al, PNAS, 1998



Integration

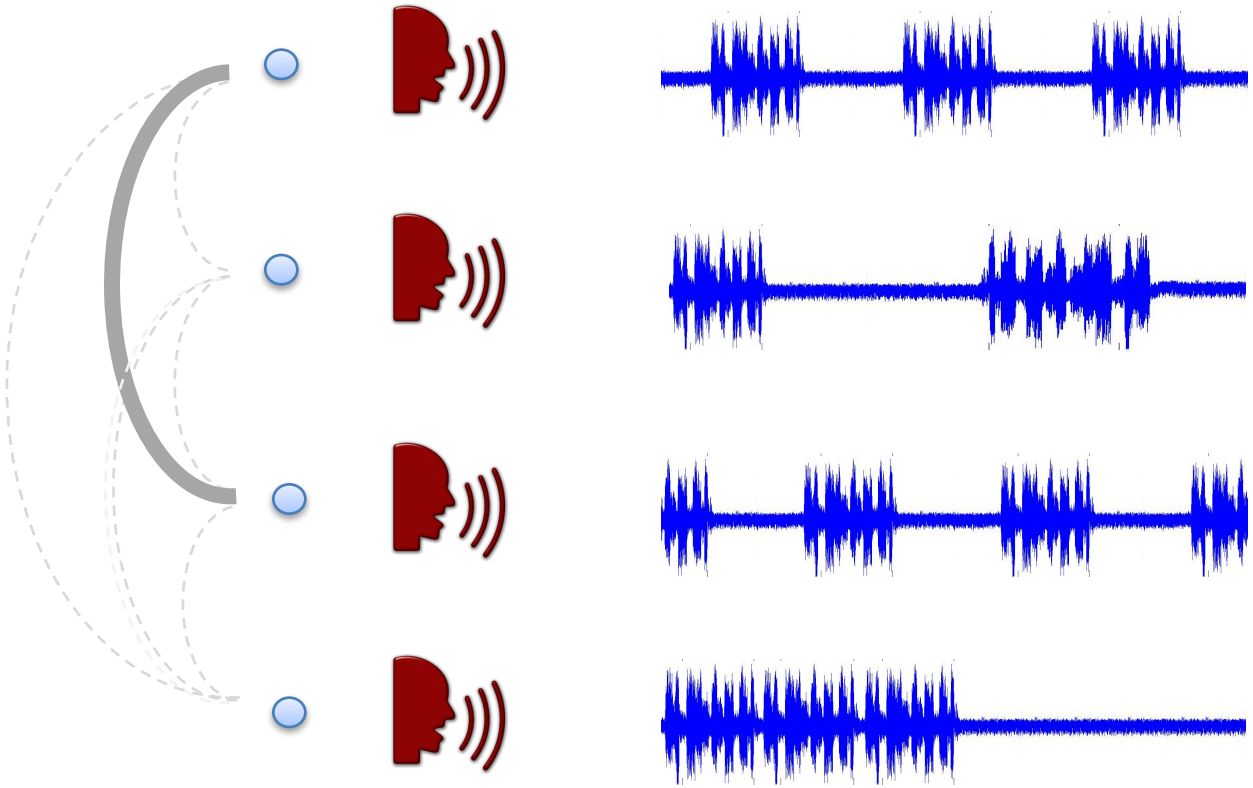
Bassett & Bullmore, PNAS, 2006

Graph analysis of functional brain networks



De Vico Fallani et al, Phil Trans Royal Soc B, 2014

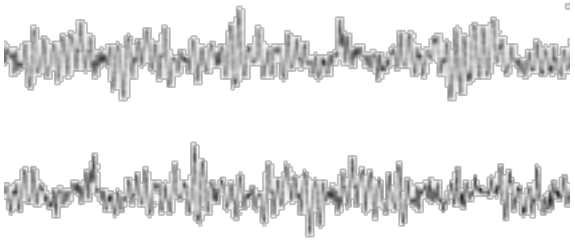
Inferring connectivity from signals



Functional connectivity

x(t)

y(t)

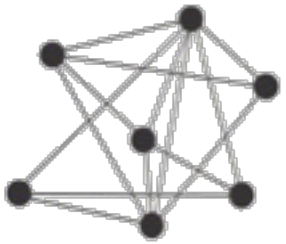


Normalized cross-covariance

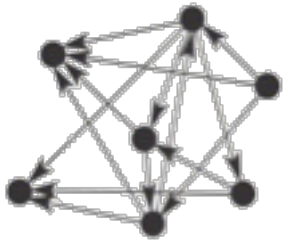
$$C(x,y) = \frac{\sum_{t=1}^{T}(x(t)-\mu_x)(y(t)-\mu_y)}{\sigma_x \sigma_y}$$

Granger-causality (AR modeling)

$$G_{x\to y} = \ln\left(\frac{\mathrm{var}(e_y)}{\mathrm{var}(e_{xy})}\right)$$

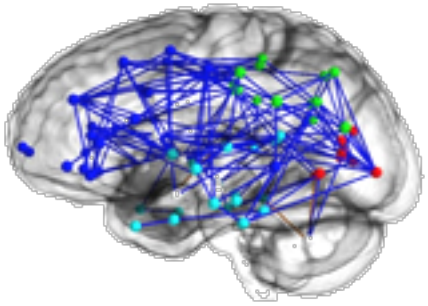


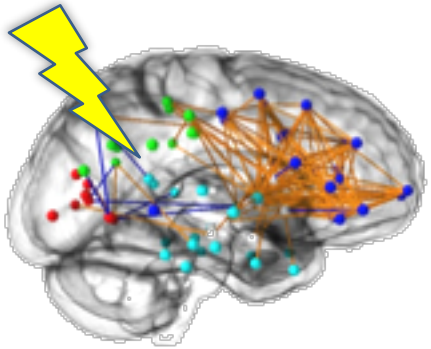
Synchronization (undirected)



Propagation (directed)

Cortical reorganization after stroke





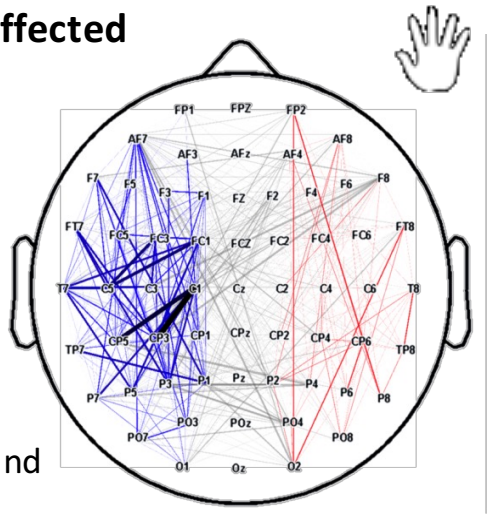
Disability

Motor Imagery

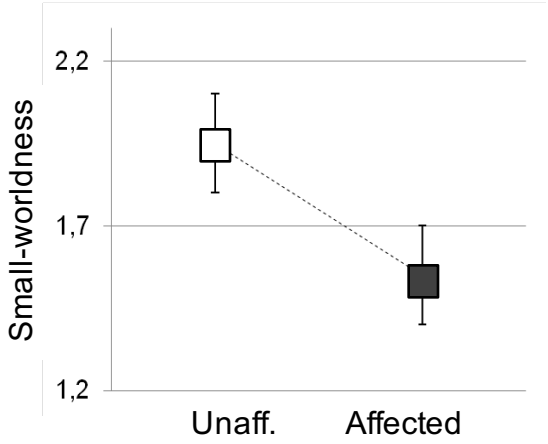
(Pfurtsheller and Neuper, Neurosci Lett, 1997)

Reduced network efficiency and outcome prediction
(Macroscale)

Unaffected

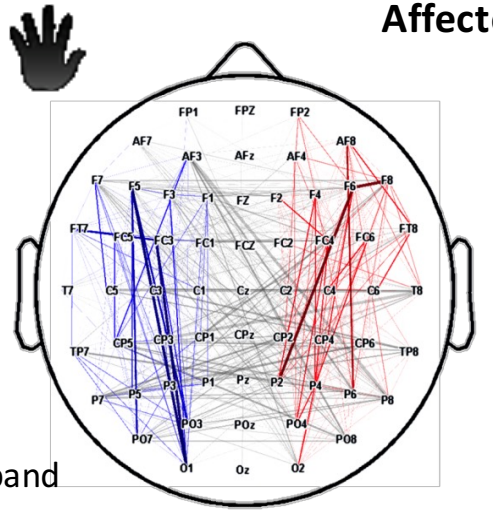


β band

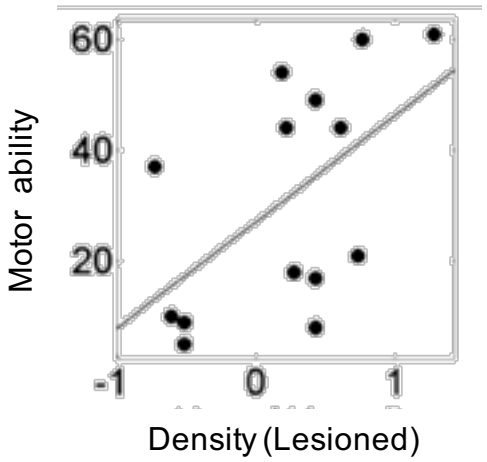


p = 0.025

Affected



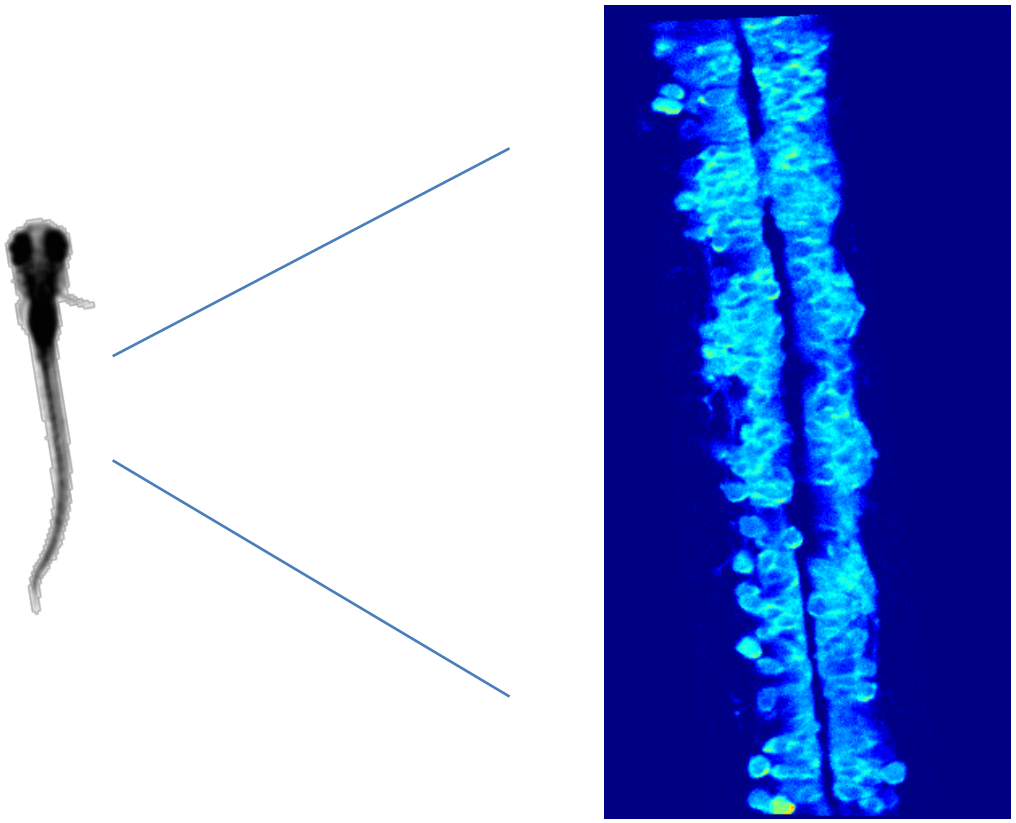
β band



R = 0.53
p = 0.04

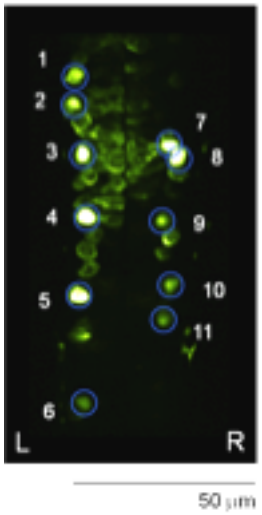
De Vico Fallani et al, Neuroimage, 2013

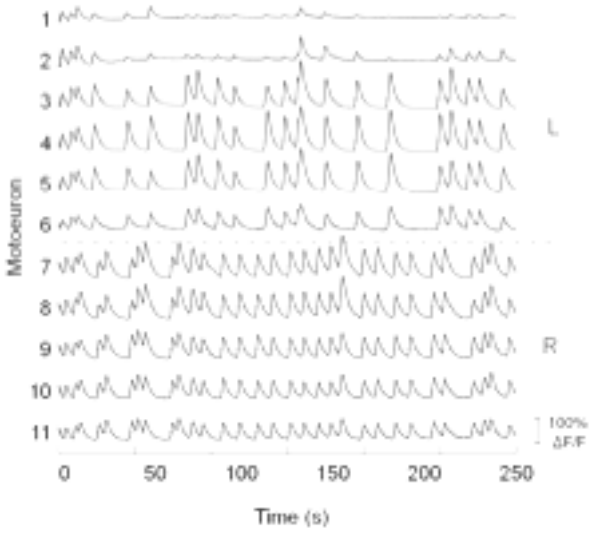
Functional organization of motoneurons
(Microscale)

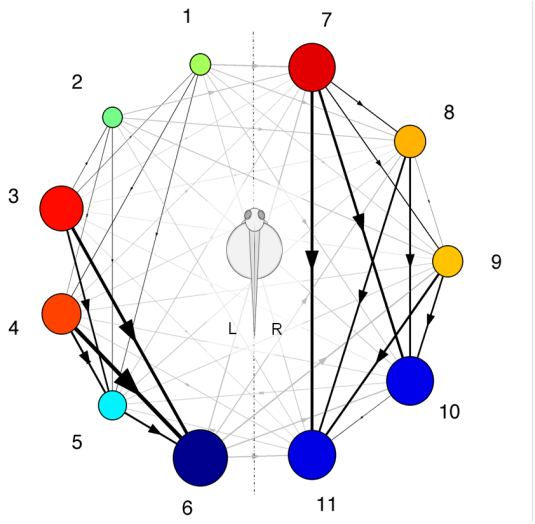


5x

Hierarchical node centrality





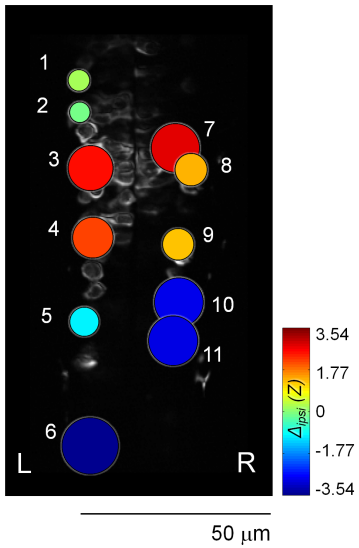


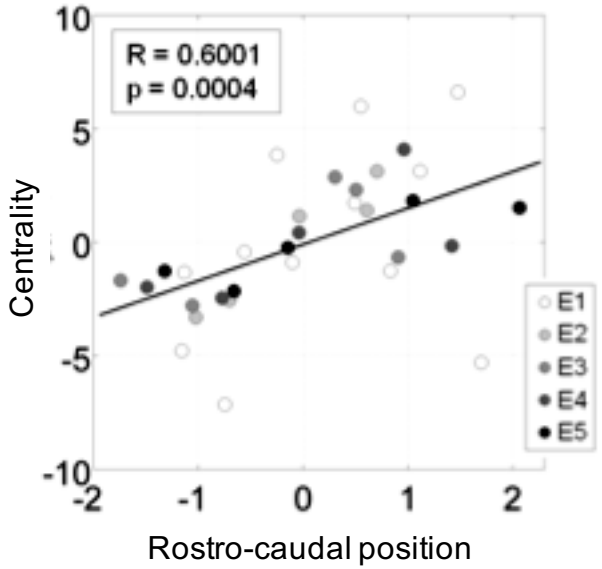
Centrality

$$C(i) = k_{out}(i) - k_{in}(i)$$

C(i) > 0 → transmitter

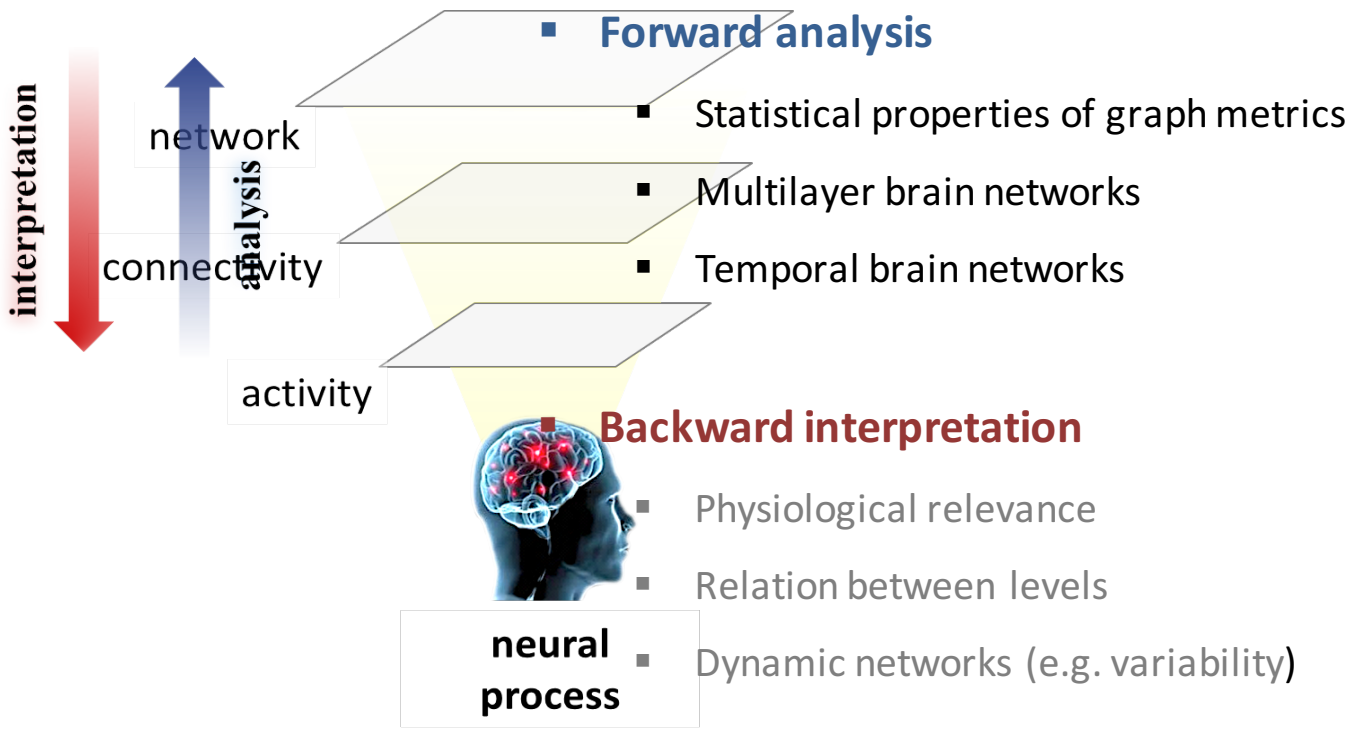
C(i) < 0 → receiver



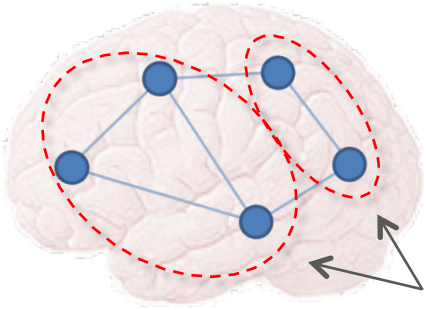


De Vico Fallani et al, IEEE TNSRE, 2014

Some open issues



Statistical methods for network clustering



Clusters

$$\left\{T^*_{i,1},\ldots,T^*_{i,N}\right\} \approx \text{Multinomial}(k_i; T_{i,1},\ldots,T_{i,N})$$

R bootstrap replicates (MC sampling)

$$\left\{\mathbf{T}^*_1,\ldots,\mathbf{T}^*_R\right\} \rightarrow \left\{\mathbf{D}^*_1,\ldots,\mathbf{D}^*_R\right\} \rightarrow \overline{\mathbf{D}^*} = \sum_{r=1}^{R} \mathbf{D}^*_r$$

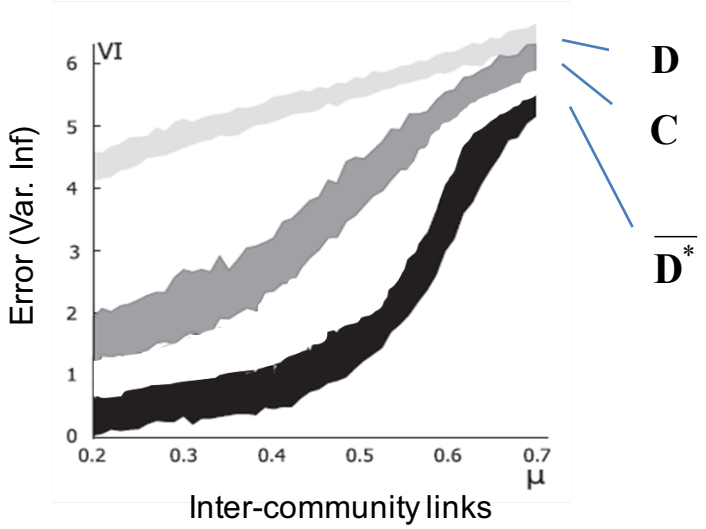
Transition matrix **T**

$$T_{i,j} = C_{i,j} / k_i$$ ← Node degree

Distance matrix **D**

$$D_{i,j} \cong \sqrt{\sum_{l=1}^{o} \lambda_l^2 [v_l(i) - v_l(j)]^2}$$

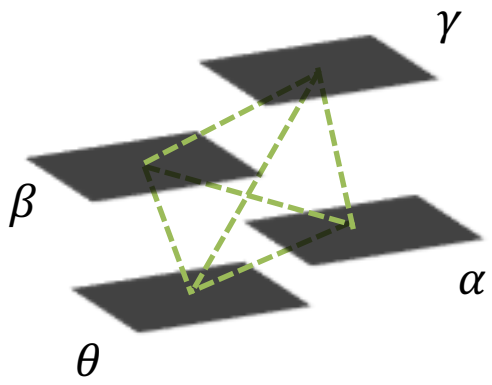
Synthetic networks (N=500, 100 iter)



De Vico Fallani et al, Phys Rev E, 2014

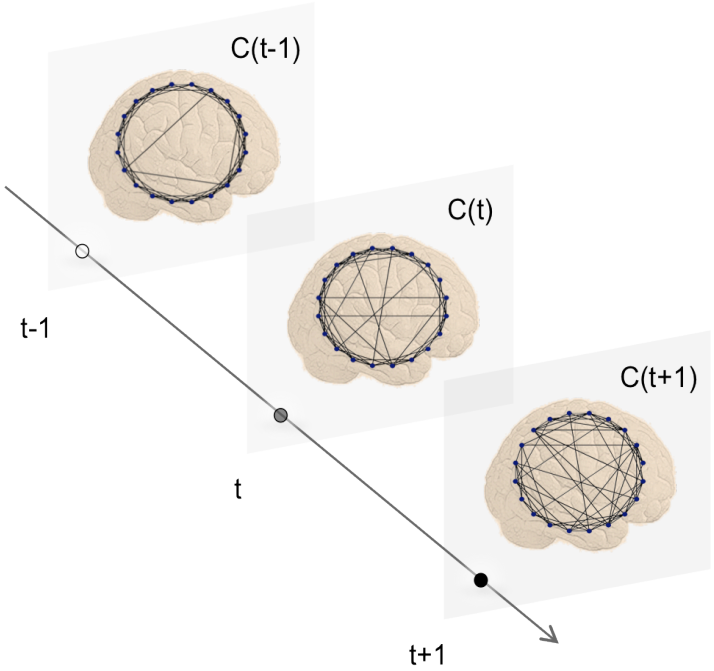
Ongoing work

Multilayer brain networks



Jeremy Guillon,
UPMC Phd student

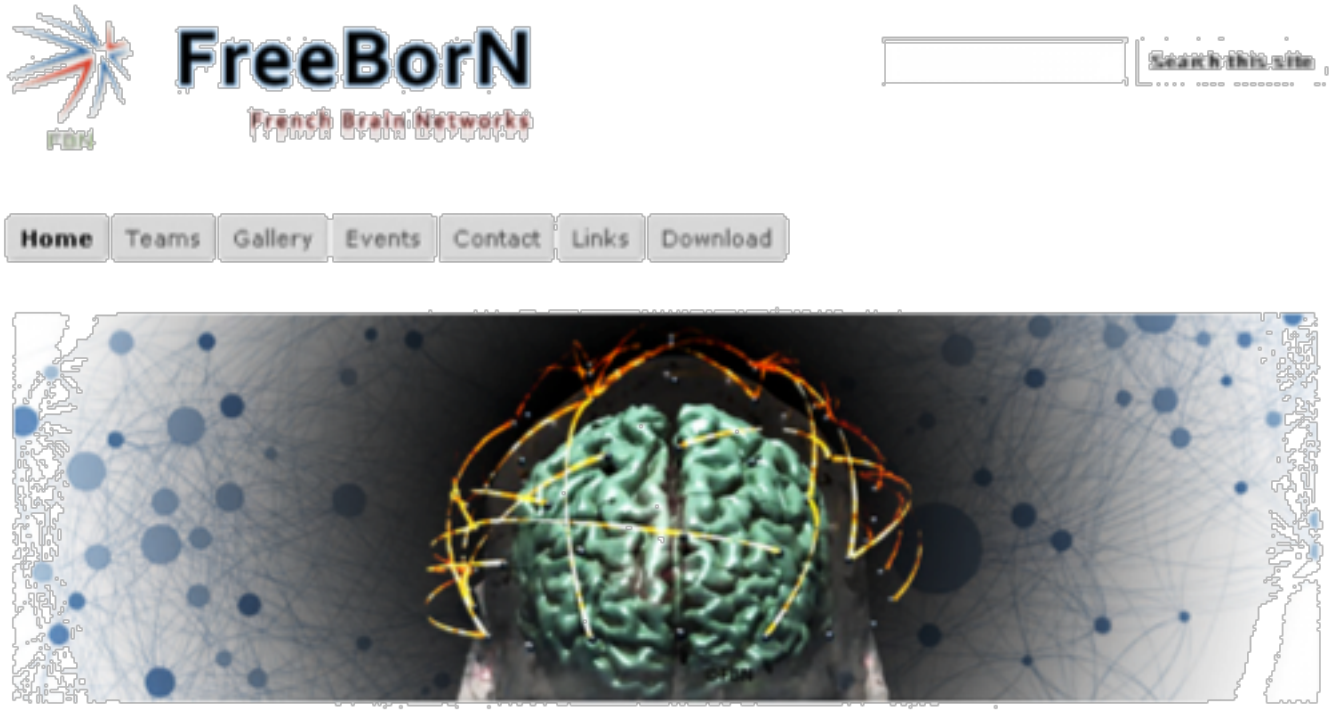
Temporal brain networks



Catalina Obando,
INRIA Phd student

Stay tuned ☺

https://sites.google.com/site/fr2eborn/



Articles, Routines, Data, Events, Job offers, …

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- ….