

Scale resolved analysis of brain functional connectivity networks with spectral entropies

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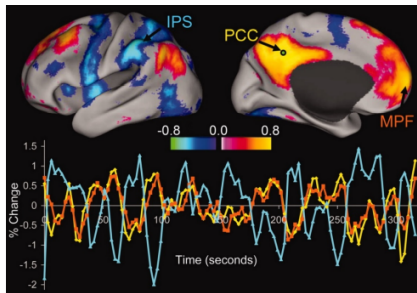
Center for Neuroscience and Cognitive Systems
Istituto Italiano di Tecnologia

Lipari, July 15, 2019

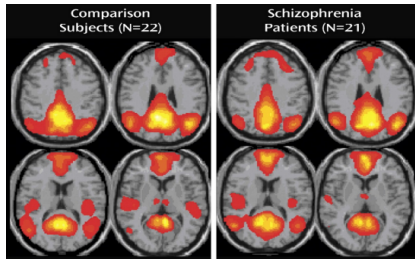


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Resting state brain networks



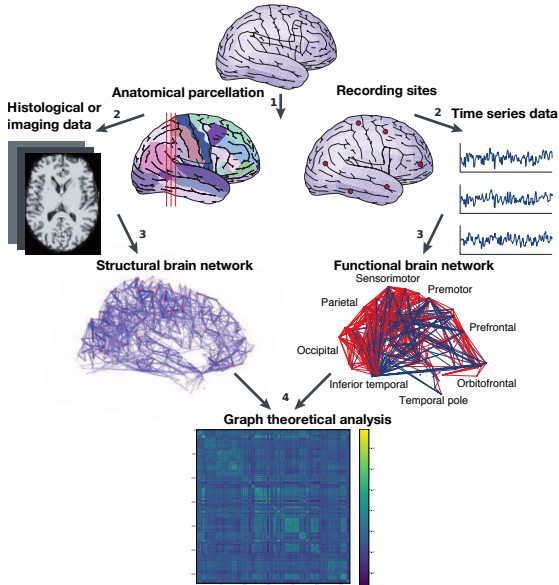
Fox et al. 2005



Greicius et al. 2007

- Spontaneous fluctuations of BOLD fMRI signal
- Subject at rest, 5 minutes.
- Effects of motion.
- Effects of thresholding.
- Effects of diseases.

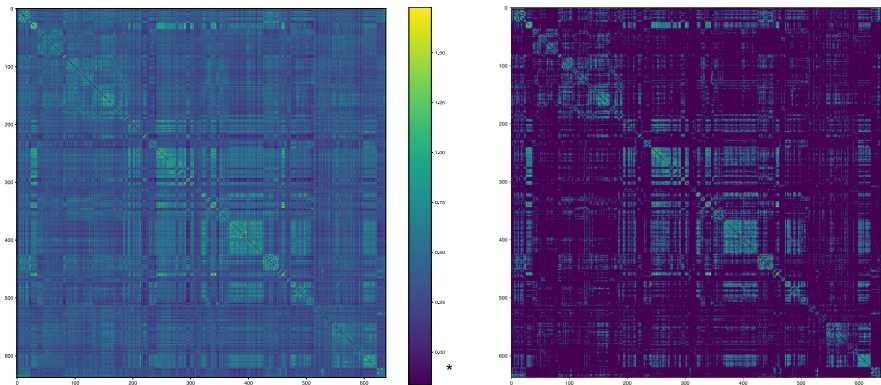
Graph theory to access information in rs-fMRI



Continuous association measure (correlation, mutual information, coherence etc...)

How to compare brain networks?

- Weights are positive and negative.
- Matrices are dense (computationally hard).
- Spurious correlations (e.g. motion).



Before thresholding

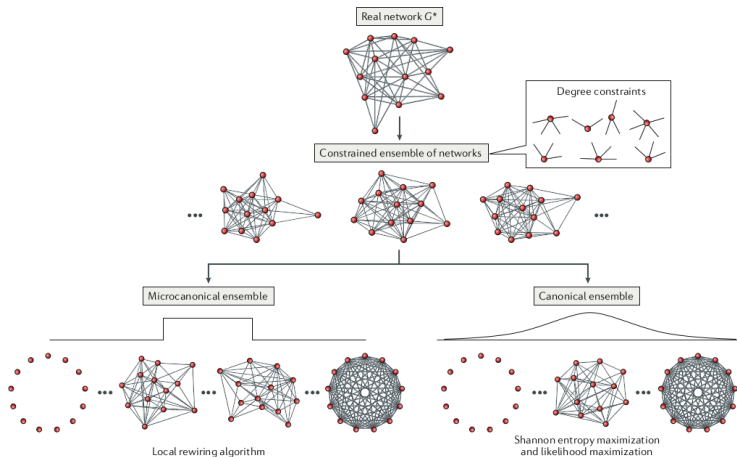
After thresholding

Appropriate null models are needed

MaxEnt framework helps

- Maximally non-committal to missing information.
- How far are networks from random?
- Detection of significant structural patterns in real networks.
- Maximum Entropy Random Graphs (classical)
- Spectral entropies (quantum)

Probability distributions on graphs



Maximize entropy $S(\mathcal{G}) = -\sum_{G \in \mathcal{G}} P(G) \ln P(G)$ with constraints.

$$P(G) = \frac{e^{-H}}{Z}$$

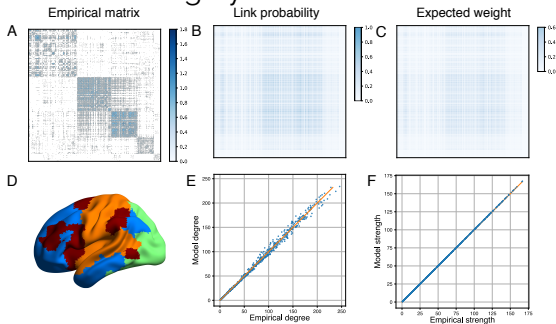
Continuous Enhanced Configuration model

- Degree sequence $k_i = \sum_j \Theta(w_{ij} - t)$
- Strength sequence $s_i = \sum_j w_{ij} \Theta(w_{ij} - t)$

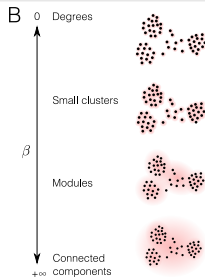
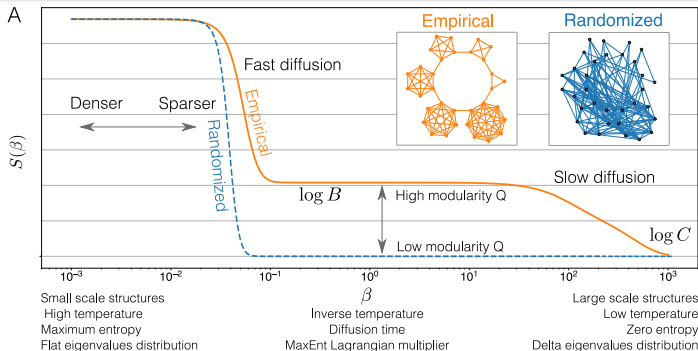
Hamiltonian: $2n$ parameters

$$H(G|\alpha, \beta) = \sum_{i < j} \alpha_{ij} \Theta(w_{ij} - t) + \beta_{ij} w_{ij} \Theta(w_{ij} - t)$$

Model fitting by maximum likelihood.



Spectral entropies and diffusion on networks



Von Neumann entropy and density

$$S(\rho) = -\text{Tr}[\rho \ln \rho] \quad \rho = \frac{e^{-\beta \mathbf{L}}}{\text{Tr}[e^{-\beta \mathbf{L}}]}$$

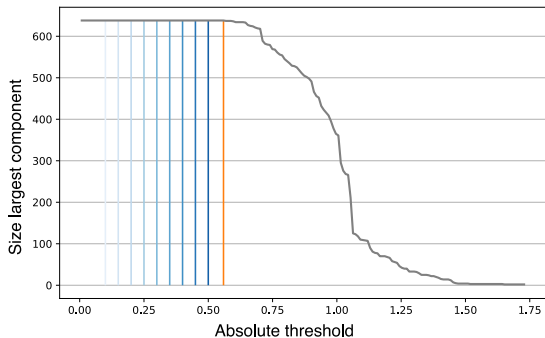
Shaped by Laplacian eigenvalues (spectral gap)

Von Neumann relative entropy: **scale resolved network comparison**

$$S(\rho || \sigma) = \text{Tr}[\rho (\ln \rho - \ln \sigma)]$$

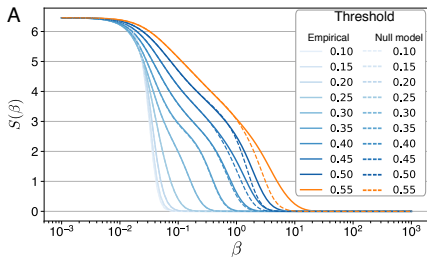
Network thresholding

- Sparsification to reduce effects of experimental noise.
- Computationally tractable.
- rs-fMRI networks, N=638, 24 healthy subjects.

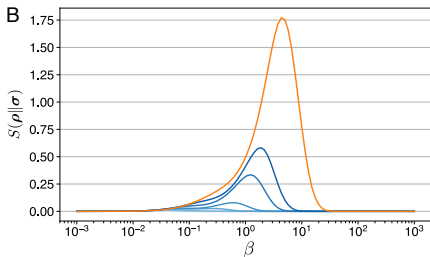


Effects of network thresholding

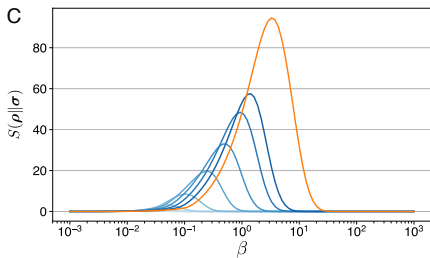
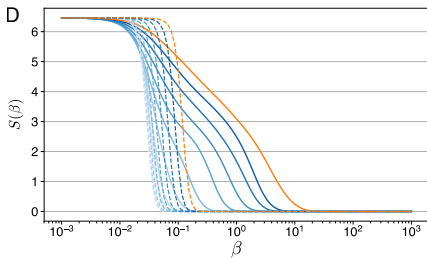
Spectral entropy



Relative entropy



Weighted Enhanced
Configuration Model

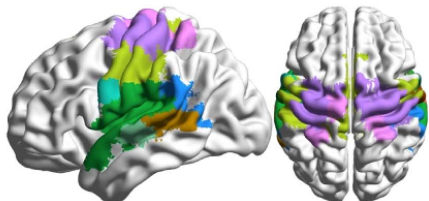
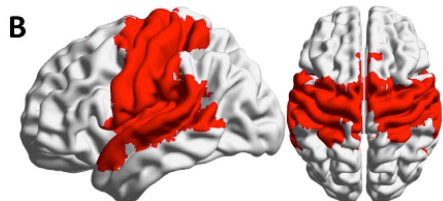
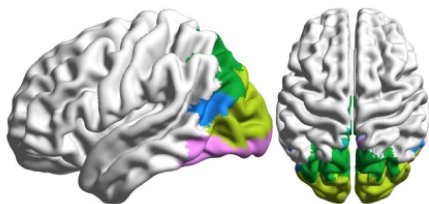
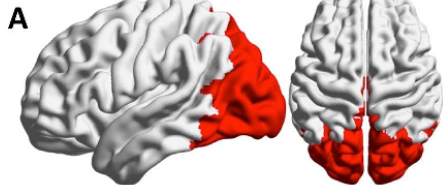


Weighted Random
Graph Model

Disruption of modular architecture in schizophrenia

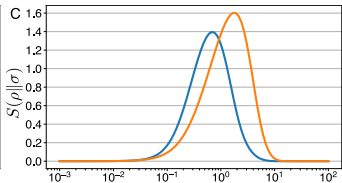
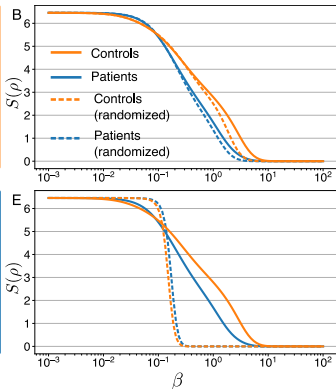
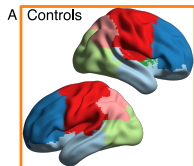
Control

Patient

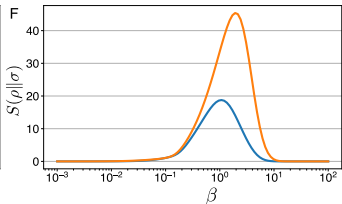
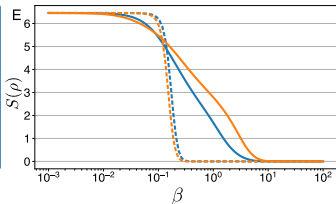
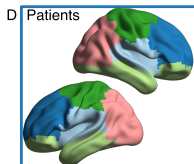


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Effects of disease: schizophrenia



Weighted Enhanced
Configuration Model

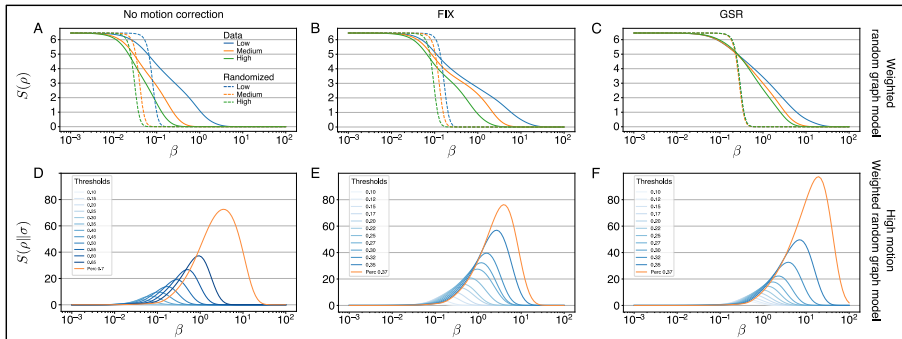
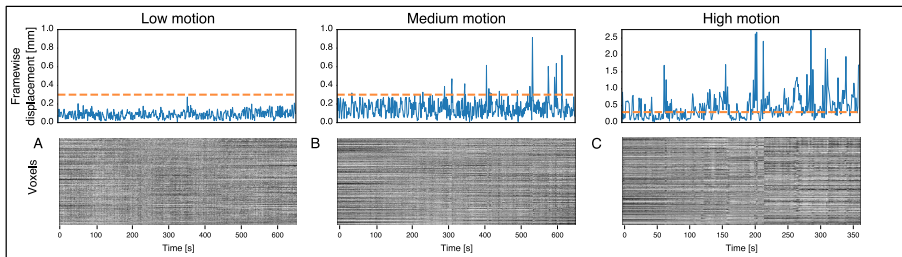


Weighted Random
Graph Model

Motion and its correction

- Long range spurious correlation
- Pipelines for correction
- Aggressive vs. conservative

Effects of motion



Conclusions

- rs-fMRI null models
- x
- y