Modelling flexible changes between network configurations in task-free brain activity

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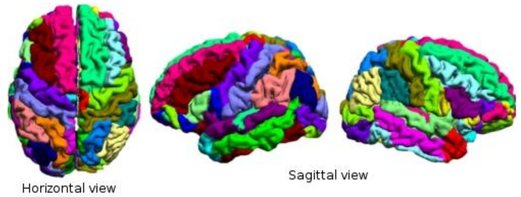
1 Aim

We aim to reproduce resting-state functional-connectivity (FC) networks modeling (neural and BOLD) activity of the interacting cortical regions. We focus on the topology of the network interactions as a main ingredient of our model based on experimental data taking into account both anatomical and functional connectivity. Hence, important information about the presence/absence of direct neural connections within functionally connected nodes is included in the model. Controlling for direct neural links in functional networks allows us to test the hypothesis that remote synchronization of the neural activity, arising from the underlying topology of the network interactions, accounts for the FC between distant cortical regions.

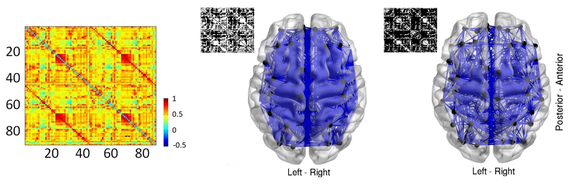
2 Model Ingredients

Empirical Data

We consider empirically derived resting-state functional network from fMRI data together with anatomical connectivity network derived from diffusion-weighted MRI data to embed oscillators into a realistic brain structure.



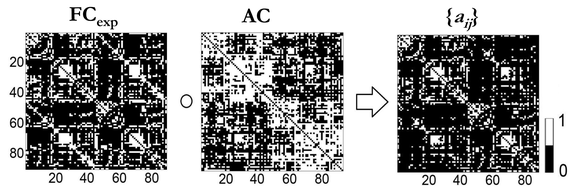
Empirical **functional networks** after parcellation of the cerebral cortex into 90 regions using the AAL cortical surface template (above). Tzourio-Mazoyer et al., Neuroimage 15, 273 (2002).



Left: Functional connectivity (FC) matrix constructed by calculating Pearson correlations on all pairwise all pairwise combinations of the BOLD data from 90 AAL cortical regions. **Middle/Right**: Visualization of thresholded matrices in anatomical space with links between connected regions . Binarized FC matrix for two thresholds r: Middle: r = 0.48, Right: r = 0.56. (White - significant correlations).

3 Model Ingredients

Empirical Data



Coupling topology $\{a_{ij}\}$: Element-wise multiplication of the thresholded FC and AC matrices; r = [0.48, 0.49, . . . , 0.66] and p = 0.05, respectively.

Network model of phase oscillators

$$\dot{\theta}_i = \omega_i + c\sum_{j=0}^{N} a_{ij}\, sin\,(\theta_i - \theta_j - \alpha_{ij})$$

θ_i - phase variable; ω_i - intrinsic frequency; c - fixed coupling; strength; α_{ij} - distance-dependent phase offset

$$R(t) = \left|\langle e^{i\theta_j(t)}\rangle\right| \qquad \begin{matrix} R(t) = 1 \text{ (synchronized state)} \\ R(t) = 0 \text{ (desynchronized state)} \end{matrix}$$

Neural activity: $V_i(t) = \sin(\theta_i(t))$
fMRI BOLD activity: Balloon-Windkessel model

Network model of FitzHugh-Nagumo oscillators

$$\dot{u}_i = g(u_i, v_i) + c\sum_{j=1}^{N} a_{ij} u_j(t - \Delta t_{ij}) + n_u$$

$$\dot{v}_i = h(u_i, v_i) + n_v$$

Summary

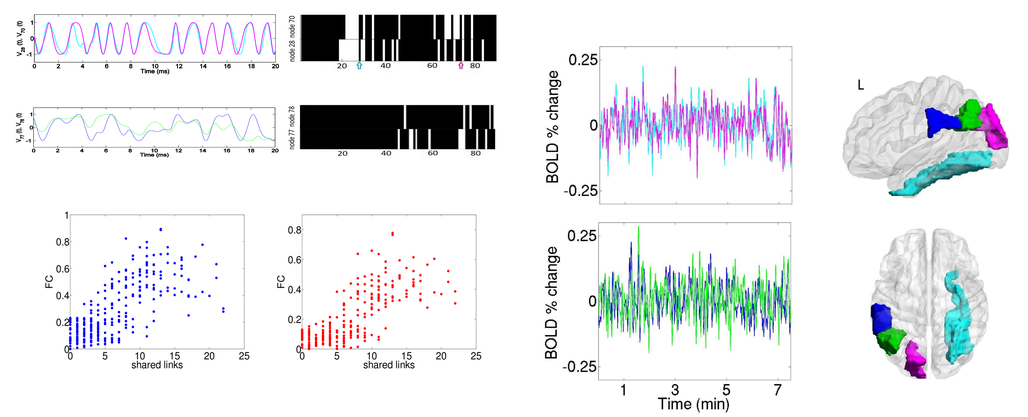
We demonstrate that fast flexible changes in neural network synchrony contribute to the emergence of correlated activity between remote brain regions.

We show that such changes reflect alternations between network synchronized and less synchronized state. We also show that the level of synchrony between remote network nodes strongly correlates with the corresponding number of shared connections.

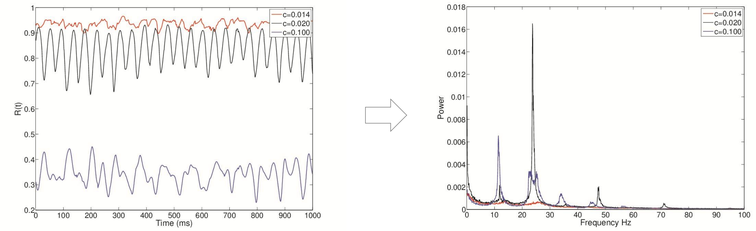
References

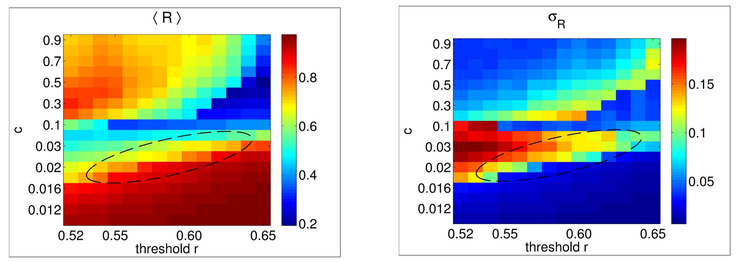
Vuksanovic V and Hoevel P 2016 *Cogn Neurodyn*
Vuksanovic V and Hoevel P 2015 *Chaos* 25023116.
Vuksanovic V and Hoevel P 2014 *NeuroImage* 97 1-8.

4 Results

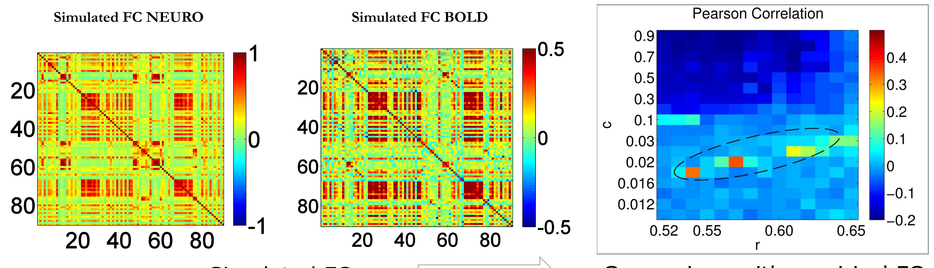


Time series: Remote synchrony - indirect interactions





Order parameter (R): Point of operation - variability/flexibility



Simulated FC → Comparison with empirical FC