

Patterns of partial synchronization and multiscale dynamics in the human connectome core network

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Brain imaging data and the availability of the human connectome's structure have enabled research into global-scale brain processes. In this regard, synchronization processes are increasingly studied in attempts to reveal key mechanisms across different aspects of global brain function and brain disorders.

We investigate synchronization in the human connectome core network, where phase oscillators are located at network nodes (brain regions) and interact via weighted edges (neuronal bundles). It comprises the central part of the connectome, associated with the eight key nodes, known as brain hubs, which transmit information between different brain regions. We present recent results [1] on the topology and spectral properties of the network, which are relevant to synchronisation processes, along with simulations of the Kuramoto oscillators' dynamics on it [2] as the global pairwise coupling is varied.

The study reveals two mechanisms underlying partial synchronization as a relevant pattern in human connectomes. In particular, at negative pairwise couplings, partially synchronised small groups of nodes occur, linked to phase frustration; meanwhile, at positive couplings below the master-stability threshold, the cluster synchronisation mechanisms dominate. Using Laplacian eigenvector localisation methods to identify nodes within these topology-related clusters helps reveal the roles of brain hubs in these processes. Both patterns induce multiscale oscillations in the temporal evolution of the global phase order parameter. Multifractal analysis of the order parameter, along with its related singularity spectra, quantifies the difference between the two mechanisms through their dependence on the coupling strength and sign, as well as the edge weights.

References:

- [1] B Tadić, MM Dankulov, R Melnik, Synchronisation of clusters around brain hubs promotes multiscale phase oscillations in the human connectome, *Chaos, Solitons & Fractals* 201, 117261 (2025)
- [2] B Tadić, M Chutani, N Gupte, Multiscale fractality in partial phase synchronisation on simplicial complexes around brain hubs, *Chaos, Solitons & Fractals* 160, 112201 (2022)