Tytuł projektu

Dynamika przejść pomiędzy mikrostanami w sieciach neuronowych.

Project title

Dynamics of microstates transitions in neural networks.

Dyscyplina /Area of science

Nauki fizyczne

PROJECT DESCRIPTION

Zgłaszający projekt/ Author of the project

Prof. Włodzisław Duch

Project goals

- To use models of attractor neural networks for characterization of basins of attractors and transitions between attractor states.
- To use nonlinear recurrence analysis methods for analysis of dynamics of microstates transitions between large-scale real functional brain networks.
- To link microstates derived from EEG/MEG analysis with structural connectomes and attractor states in neural networks.
- To decompose fMRI functional connectivity states into a combination of fast microstates derived from EEG.
- To characterize different types of abnormal dynamics of neural networks in relation to the biophysical parameters characterizing neurons.

Outline

High-definition measurement of EEG creates large amounts of data and is difficult to analyze, requiring sophisticated computational methods to simulate propagation of electric potentials and magnetic fields through different types of brain tissue. Decomposition of brain activity into a series of quasi-stable microstates (lasting 60-150 ms) that can be identified in EEG/MEG signals has an important diagnostic value. A promising attempt to understand brain dynamics is based on fMRI. Tensor diffusion imaging (DTI) shows anatomical connections between different regions of the brain. Network neuroscience is using this data together with functional correlations to create graphs representing information flow. This approach can explain many phenomena, including mental disorders, intelligence, working memory and decision making. fMRI provides information about spatial distribution of active brain regions with accuracy of 1-

2 mm, but temporal resolution does not exceed 1 Hz. This means that one brain scan is averaging signals of about 10 microstates. On the other hand temporal resolution of EEG is excellent, up to 1 ms, but spatial resolution is of the order of centimeters. fMRI is very useful not only to recognize various problems with brain connectome structure but also information flow, that is determined by very complex biophysical processes responsible for neural activations.

Localization of active structures gives also a chance for therapeutic neurofeedback interventions. Real-time fMRI (rt-fMRI) based on source localization or monitoring of functional connectivity is very effective in changing behavior. Neurofeedback based on EEG signal analysis is not working as well as rt-fMRI. EEG is much more cost-effective and practical, but requires source reconstruction and localization to extract information about localized brain activity. Development of new non-linear methods of recurrence analysis of EEG microstates is of great importance. Ultimately we would like to decompose brain signals into activity of specific subnetworks with groups of neurons in well-defined anatomical locations.

We have recently developed a Matlab/Python Toolbox SupFunSim for simulations of propagation of electric potentials through various brain tissues, new method for solving inverse problems using minimum-variance pseudo-unbiased reduced-rank approach, and are able to perform source-level directed connectivity analysis, using partial directed coherence (PDC) and directed transfer function (DTF) measures to see information flow between different brain regions. We have been analyzing Human Connectome Project data to see how well this approach is able to reconstruct activity of brain subnetworks from EEG signals that after averaging is similar to functional networks derived from fMRI analysis. Non-linear recurrence analysis methods can capture dynamics of microstates transitions. The challenge that we would like to address is to investigate dynamics of attractor neural network models that explain experimental observations. Activation of specific subnetworks on connectome structures should lead to attractor states of neural networks that correspond to the EEG/MEG microstates. Building such biologically-oriented neural models would be an important step towards understanding, optimizing and even repairing brain processes.

Work plan

1. Mastering simulation techniques for biologically-oriented neural modelling, using the Emergent and The Virtual Brain simulators. Characterization of attractor states of the dynamics.
2. Mastering signal processing techniques, based on independent component analysis, tensor analysis, artifact removal and other machine learning techniques useful in EEG/MEG signal processing and classification.
3. Review of current approaches to analysis of EEG/MEG microstates and nonlinear methods derived from recurrence analysis.
4. Developing methods of signal segmentation and averaging over microstates instead of fixed time windows.

5. Mapping microstates dynamics to the activations of large-scale functional networks activated on the structural connectomes.
6. Providing signals based on activity of selected brain regions, or active brain networks, which can be useful in neurofeedback.

Literature

1. Duch, W. Mind as a shadow of neurodynamics. Physics of Life Reviews, Special Issue on "Physics of mind", Ed. F. Schoeller (in print).
2. Gravier A, Quek H.C, Duch W, Abdul Wahab, Gravier-Rymaszewska J. Neural network modelling of the influence of channelopathies on reflex visual attention. Cognitive Neurodynamics 10(1), 49-72, 2016
3. Finc, K., Bonna, K., Lewandowska, M., Wolak, T., Nikadon, J., Dreszer, J., Duch, W., Kühn, S. Transition of the functional brain network related to increasing cognitive demands. (2017). Human Brain Mapping 38 (7), 3659–3674
4. Dobosz, K., & Duch, W. (2010). Understanding neurodynamical systems via fuzzy symbolic dynamics. Neural Networks, 23(4), 487–496.

Required initial knowledge and skills of the PhD candidate

- ➔ Analytical thinking.
- ➔ Eager to learn and focus on the goals.
- ➔ Skills in programming, preferably in Python and Matlab.
- ➔ Understanding of principles of neural systems.

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Proponowani promotorzy i mentorzy/prospective supervisors

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