A Transient Model for Neuronal Oscillations
Carlos A. Loza, Jose C. Principe
Computational NeuroEngineering Laboratory, University of Florida, Gainesville, FL, USA

Background: Classical signal processing methods for neuronal oscillations, such as EEG and LFP, usually rely on the strong restrictive assumptions of stationarity and ergodicity. However, electrical potentials from the brain are well known for displaying statistical properties that vary over time giving rise to transient patterns [1]. Moreover, decomposition methods in the literature not only utilize these erroneous assumptions, but they also introduce processing windows that smear the temporal information encoded in the structure of the signal. We propose a transient model that poses a single EEG trace as the result of the noisy addition of reoccurring, transient events over time and frequency bands (Fig. 1). This enables to preserve the superior temporal resolution of EEG while incorporating additional features to the model, such as amplitude, frequency, duration, and modulation-based measures related to relevant phasic events. These measures can, consequently, be utilized to interpret behavior and stimuli encoding in the brain at a macroscopic level beyond single unit paradigms.

Methods: Sparse decomposition and dictionary learning [2] techniques are utilized in order to learn the relevant events directly from the EEG traces. The algorithms are completely window-free, data-driven and do not impose pre-defined templates, such as complex sinusoids or wavelets. In addition, based on the clinical interpretation [3] and local interaction of principal cells and interneurons, we restrict the possible extracted snippets to modulated, spindle-like shape patterns. This is not only neurophysiologically sound, but it also accelerates the convergence of the proposed techniques. Afterward, the extracted features are post-processed to extract relevant statistics. For instance, behavior and topographic discriminability is assessed by computing the statistical relevance values.

Results: The proposed framework is applied to BCI competition dataset III. The decomposition features preserve amplitude-based relevance ($p = 2.68 \times 10^{-8}, p = 3.48 \times 10^{-7}$) observed in similar studies. Furthermore, the novel joint amplitude-timing space provides discriminability over time by modeling the learned properties as samples from a continuous Gaussian Mixture Model.

Conclusions: We provide a transient model for neuronal oscillations where the relevant features are extracted automatically from single-channel EEG traces. In particular, the system does not assume stationarity and does not utilize pre-defined templates for the decomposition. This opens the door for further innovative analysis and processing where the superior temporal resolution of the phasic events can be mapped to spike activity and fine-tuned behavioral tasks. In addition, the findings provide richer information than the classical amplitude-based decomposition methods; hence, allowing multivariate EEG analysis.

References:

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