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GPU-based high-performance computing of multichannel EEG phase wavelet synchronization.

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Abstract

The work is devoted to GPU-based high performance realization of algorithm for wavelet phase synchronization. Wavelet phase coherence was applied for analyzing brain activity in states with different degrees of mental and sensory attention. In the analysis of electroencephalographic correlates of mental states, as a rule the focus is on the analysis of the spectral power of a quasi-stationary EEG or task-related power of time-frequency EEG spectra. The analysis of the wavelet phase coherence provides additional information on the organization of brain activity, but requires more computing time. Fast implementation can simplify the use of this method in practice.

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Keywords: Graphics processing unit(GPU), wavelet phase coherence, EEG analysis, analysis of non-stationary signals

1 Introduction

The main approach in the task of EEG correlates of states with different degrees of mental and sensory attention analysis is a spectral power computation ([15], [6], [3] and etc.) Task-related power, time-frequency spectra are the event-related modification of EEG spectral power ([2], [1]). Although some studies have also examined the EEG coherence parameters ([6], [3]), the number of papers on the analysis of coherence in mental states is still rather limited. At the same time, the parameters of coherence of brain electrical activity are usually considered as an effective indicator of the process of involvement of different brain zones in the realization of cognitive processes ([12]).

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In the modern literature, the methods of evoked potentials analysis are used for the study of mental attention ([2], [1]). It relevant to utilize methods that able to track changes in the connectivity of brain processes in time and analysis based on wavelet phase coherence satisfies the requirements.

Wavelet-phase synchronization for more than a decade is used to describe systems of coupled oscillators [8]. The reason for such popularity is the fact that classical approaches to synchronization analysis are extremely sensitive to the presence of noise in the processed data. Thus, it is difficult to analyze the data of real experiments. In particular, EEG signals generally belong to the class of chaotic signals, which excludes the use of the classical theory of synchronization.

About 20 years ago, it was proposed to use a wavelet cross-spectrum power to detect correlated signals between leads at certain frequencies [4]. At the same time, it was demonstrated that analysis of the phase component allows us to see stable structures that could not be obtained from the amplitude analysis [9]. Unfortunately, despite such a long time, these approaches didn't become widely used due to the complexity of the wavelet theory and the lack of software.

In recent years, graphics processing units (GPU) have made it possible to significantly accelerate computing, by using multi-threading, which allows the simultaneous execution of thousands of nodes. Along with the development of the hardware part, open source interpreted programming languages (like Python and R) have developed. They have an unquestionable advantages in simplicity and flexibility, but characterized by low computational efficiency. These problems partly overcomed by fast implementations of group operations, such as an apply in the R language or groupby in python, but their capabilities are modest enough. Third-party libraries also often have modules written in low-level languages and support a big set of functions that can be applied to the data arrays.

Further development of this approach is the implementation of symbolic calculations realized in such libraries as theano, tensorflow, mxnet, etc. Although these libraries are primarily intended for machine learning tasks, their use for other computational tasks is also possible [14]. With using such libraries, the researcher continues to use the simplicity and flexibility of the interpreted language, however, parts of the code that require compilation procedures appeared, as well as strict specification of data types and tracking of data type compatibility within code blocks to avoid errors at the graph compilation stage [7]. All the above frameworks support calculations on the CUDA GPU, while the developer does not think about the organization of threads on the device and the placement of data arrays in its memory blocks.

2 Data preprocessing

The study involved 29 healthy right-handed subjects (19 women and 10 men). Two types of task were investigated: reproductive imagination or memory (RI) and productive imagination. Before assigning to the reproductive imagination, the subjects looked in and memorized color images and corresponding nouns (e.g.: an apple, a bee, etc.). After that the subjects were consistently presented with words and asked to remember and visualize the appropriate image against the background of the computer's white screen. In the task for the productive imagination (PI), the subject was consistently presented with two words (for example apple and bee) and, looking at the computer's white screen, asked to visualize a chimera image corresponding to two words simultaneously (for example: an apple with wings of a bee). When the subjects could remember or imagine the corresponding image, they pressed the button. The words were presented in black letters on a white background. Tasks PI and RI were presented in trials, each trial consists of 80 probes. The pre-stimulus interval is 300 ms, the duration of the first