

Quantitative and Automatic Analysis of Neurological Signals and Images of Cognitive Interest

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Abstract. A research project is briefly described aiming at the introduction and application of mathematical and automatic methods to the study of the different levels of consciousness in the human brain. The first part of this communication includes a short review of two approaches recently proposed in the field of neurosciences. The second part summarizes three data analysis methods that appear as possibly powerful tools for the investigation. These methods regard one-dimensional signals, images, and textual data, respectively.

Keywords: Signal Processing, Image Processing, Text Analysis, Cognitive Science, Electroencephalogram, Consciousness.

This communication briefly introduces a research project which involves researchers of the Group of Computational Intelligence & Machine Learning of the Computer Science Department and researchers of the Signals & Images Laboratory of the Institute of Information Science and Technologies of the National Research Council. This project aims at the proposal and implementation of mathematical and automatic methods for the study of different levels of consciousness in the human brain.

This communication is divided into two parts.

The first part is dedicated to a brief review of two approaches that have been recently proposed in the rapidly advancing research field regarding the neural basis of consciousness. Among the numerous important contributions, we have chosen these two approaches because we consider them as particularly significant for our project. We will add a short reflection on the primary role played by methods proper of computer science for the cognitive study of consciousness levels.

The second part summarizes three data analysis techniques that we have implemented and can be viewed as promising tools for the research project. These techniques were proposed in three different environments: (a) the “Biopatterns” Project, in which the Group of Computational Intelligence & Machine Learning participated under the guide of Professor Antonina Starita; (b) the “Heartfaid” Project, whose consortium included the Signals & Images Laboratory; (c) collaborations in cognitive research established within the International Association for the Study of Dreams.

We now shortly describe the two chosen instances of important recent approaches.

The first example is given by a study of the brain responses to sensory stimuli, specifically acoustic stimuli, performed by a French group [1]. The Authors analyzed the responses to rare deviant stimuli delivered within a serial flow of frequent standard stimuli. They simultaneously recorded Functional Magnetic Resonance Images (fMRI), Intracerebral Local Field Potentials, and Event-Related Potentials. The experimental protocol aimed at separating responses due to neural systems characterized by different levels of consciousness. Violations of local regularity elicited effects “suggestive of an automatic, nonconscious, and encapsulated mode of processing”. Violations of global regularity evoked a very different response given by conscious brain subsystems. The differences regarded waveform as well as time latency.

The other article we now consider is a review paper by Raichle, a neurologist at the Washington University in St. Louis, describing a “paradigm shift in functional brain imaging” [2]. This paper focuses on researches that showed, by means of fMRI, that a set of brain regions, called “Default Mode Network” (DMN), decreased their activity across a wide array of task conditions with respect to passive control conditions. Blood-Oxygen-Level Dependent (BOLD) fluctuations recorded from distant brain areas belonging to the DMN presented a high correlation. The DMN system therefore appears as providing a background for the emergence of conscious activity.

For both of these examples, the processing of data required advanced methods for feature extraction, data combination, data representation, and statistical analysis.

We now mention three methods for signal and image processing that can be useful for our project.

For the purposes of the “Biopattern” Project, we implemented a method for the detection of transient events in spontaneous electroencephalogram (EEG) [3]. After a computation of signal frequency components, performed according to conventional frequency band assignments, an event was defined as a transient increase in the activity amplitude in any frequency band. Another kind of events consisted in transient decreases in the correlation between pairs of EEG traces. The detected events, together with their main attributes, were stored as records in a database. The statistical analyses were carried out on the results of queries to this database.

For the purposes of the “Heartfaid” Project we implemented a method for image segmentation [4] that can also applied to neuroimages. The segmentation procedure consisted of two stages: the application of local thresholding based on criteria mimicking visual analysis, and the construction of a contour through an active contour method consisting in the minimization of a suitable “Energy Function”. The evolving contour was represented as the zero-level of a time-varying function defined over the image.

In addition to one-dimensional data and images, we proposed methods for processing textual data of cognitive interest [5]. In particular, a method for the recognition of possible links between the various memory sources of sleep mentation was applied to dream reports and to associations with the various dream items provided by subjects woken from the Rapid-Eye-Movement stage.

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