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Towards a Semantic Framework for an Integrative Description of Neuroscience Patterns and Studies: A Case for Emotion-Related Data

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Abstract. The continuously increasing number of neuroscience studies and the difficulties associated with searching for related information and properly tracking neuroscience findings makes it imperative that one may be lead to isolated theories and findings which may be incompatible to each other or partially occluded. Semantically describing several aspects of studies in this field, such as, research groups attributes, aims of studies, experimental procedures followed, hardware and software tools utilised, acquisition systems used, as well as, the emerging neuro-physiological patterns found, may facilitate an integrative view of neuroscience theories. To this end, the current piece of work aims to provide a global theoretical framework using ontologies and semantic rules to describe neuroscience studies. Implementation details and applicability of the proof of concept are illustrated by means of an example targeting the semantic description of an emotion related study. The importance of the proposed framework in facilitating the envisaged personalised healthcare of the information society is discussed.

Keywords. semantic framework, neuroscience ontologies, knowledge management, emotional processing, affective computing

1. Introduction

Recent hardware advances have led to the development of devices capable of recording brain activity with excellent temporal resolution, as well as, neuroimaging tools which can provide very accurate spatial information. At the same time, elaborate software techniques were employed for analyzing neuroscience data in a robust way. These improvements have resulted in a wealth of research studies aiming to investigate the underlying puzzle of cognitive processes. However, in their vast majority, the aforementioned studies have, so far, failed to provide a synthesis of results and a global insight into brain function. Moreover, some of their findings are mutually incompatible [1], or difficult to utilize and further exploit. Consequently, many research efforts resulted in isolated theories or methodologies, failing to facilitate the development of a

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more general ambitious research vision in the neuroscience field, which in turn discourages the retrieval or the use of existing findings towards a proper knowledge discovery. The above points argue for the lack of and the need to develop an integrative neuroscience framework.

Moreover, there is growing evidence that the use of ontologies can facilitate the semantic description of several medical topics, since they provide knowledge representation and extraction in a structured way [2]. The Gene Ontology [3], for example, is used to describe gene sequences, while the UMLS [4] ontology is employed for the description of a wide range of medical terms. On the other hand, the MCP ontology [5] aims to contribute towards the description of biomedical problems, as well as, to their associated computerized algorithmic solutions. To this end, ontologies may offer an attractive solution for the semantic description of neuroscience patterns and studies, and, therefore, some efforts have slowly but surely emerged in literature. For instance, the NEMO [6] provides a generic framework for mining brainwave ontologies, since it is an ontology-based data modeling aiming to represent the semantics of event-related potential (ERP) data. Brain cortex anatomy ontologies [7, 8] were developed in order to semantically describe brain structures. The NIFSD ontology [9] (National Information Framework Standard), supported also by the NIH Institutes and Centers for Neuroscience Research, is used to perform ontology based search over neuroscience data sources. Moreover, there are several research activities for automated mark up of emotions in text [10], as well as, emotion descriptions [11].

Towards an integrative view of neuroscience theory, several aspects of the nervous system must be taken into consideration. For this to occur, fusion of multi-physiological recordings and processing methodologies are essential pre-requisites [12]. For example, the most common way to study the electroencephalographic (EEG) activity induced by stimuli is the study of the ERPs. However, frequency changes in ERPs may be analysed by studying the so-called event-related synchronization (ERS) and desynchronization (ERD). Event-related oscillations (EROs) of certain brain frequencies may be a promising approach for the creation of the integrative neuroscience. Apart from brain signals (central nervous system recordings), several autonomic measures may provide indices of cognitive functions as well. As a consequence, a plethora of neuroscience studies has been published attempting to employ the above feature categories for studying cognitive tasks.

This piece of work aims to contribute in the efforts of integrative neurophysiology by providing a theoretical framework for the semantic description of the neuro-physiological patterns, as well as, with the structured description of the isolated neuroscience studies and their experimental protocols. A first proof of concept towards applying the proposed framework in the context of an emotion recognition protocol is also included. Implementation details and applicability of the approach are illustrated by targeting the semantic description of this emotion related study. The importance of the proposed framework in facilitating the envisaged personalised healthcare of the information society and the medical informatics research community is discussed.

2. Framework Components Description

The proposed framework employs a number of different, reusable ontologies for the description of the various sub-components. The use of ontologies which are based on Description Logic (DL) was thought to be advantageous herein and, therefore, was followed [5]. The most common language to formalize semantic web ontologies is the OWL and particularly the OWL-DL subset which is based on First Order Logic (FOL) [13]. These include definition of concepts, roles, classes, axioms, properties and individuals. Moreover, knowledge discovery may be achieved by DL reasoning, which may deal with consistency checking, taxonomy reasoning and instantiation. The knowledge retrieval may be accomplished by means of semantic queries (e.g., SPARQL [14]). The semantic rules may be used in order to describe the various neuroscience aspects in a more expressive way (e.g., Semantic Web Rule Language (SWRL) which expands the axioms expressed in OWL-DL) [15].

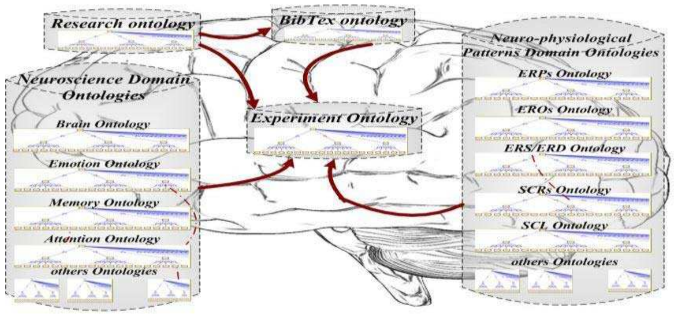

Figure 1. The Schema of the proposed theoretical framework

Figure 1 illustrates the general framework introduced for the semantic description of the neuroscience patterns and studies. The main framework ontology is the *Experiment Ontology*, which describes the research aims of a specific study. Therefore, it is linked with the *Research Ontology* to semantically describe the research team(s) conducting the specific experiment/study. Contained information about the group characteristics include the principal investigator, names of other researchers comprising the group, the activity/experiment place, study duration, as well as, and previously (available) published studies. The latter information is generated by linkage with the *Bibtex Ontology* [16] which is directly linked with the *Experiment Ontology* in order to provide the appropriate information for the citation of the study. The *Experiment Ontology* also describes the conditions of the current experiment. Following those, there exists the semantic description of the experimental aspects, as well as, the experimental domain. The experimental aspects deal with a specific task (experimental protocol parameters) conducted during the experiment, whereas the experimental domain regards the specific neuroscience subfields involved. Therefore, there is linkage with the *Neuroscience Domain Ontologies* (Figure 1) which are used in order to semantically describe specific categories of neuroscience research (*Emotion Ontology*, *Attention Ontology*, Brain *Ontology*, etc.). In addition to all these, the *Experiment Ontology* provides information about the study duration. Moreover, another piece of the *Experiment Ontology* deals with the acquisition system (ElectroEncephaloGraphy (EEG), Skin Conductance Device, etc.). For each acquisition system, more detailed information is also available and may contain, e.g., in the EEG case the number of recording electrodes, the type of the recording system, the recording sites, etc. The knowledge of the Neuro-physiological Patterns Domain can be captured by various other ontologies too. Consequently, there should be a direct link between the latter and the *Experiment Ontology* in order to provide information about the specific study.

The importance of *Neuro-physiological Patterns Domain Ontologies*, is key to this framework, because the semantics described by this set of discrete ontologies will result in knowledge sharing and discovery. The various ontologies may be the *ERPs Ontology*, *EROs Ontology*, *ERS/ERD Ontology*, *SCRs Ontology* (Skin Conductance Responses), etc. For example, the first three ontologies semantically describe the signal peak latency, amplitude and other information (e.g., positive or negative peak). In addition to all these the *EROs Ontology* may provide the semantics about the brain rhythm into consideration and its range. Regarding the ontological description of ERS/ERD may contain the frequency band that was analyzed, the interval used for baseline, its duration, the baseline energy, the study interval which will be considered for energy alterations during the experimental procedure, its duration, latency and energy value. The *SCR Ontology* may define the semantics about the response's latency, rise time, amplitude and duration. A common field for all these ontologies deals with the pre-processing procedure used in the raw data in order to extract the aforementioned neuro-physiological patterns, since even minor alterations during this phase may lead to surprisingly different features. Finally, the UMLS ontology is used in order to describe the medical concepts used in this framework.

3. Application of the Framework in the Case of an Emotion-Related Study

The proposed theoretical framework was used for the semantic description of the results obtained from the AFFECTION project [17], which proposed a scientific foundation for the robust identification of human emotional states through fusion and correlation of data. The Experiment Ontology described the emotional processing task in which subjects were passively viewing emotion evocative pictures. The aim of the specific study was emotion recognition by means of data mining and other processing techniques. This ontology also described the data acquisition system which consisted of an EEG device with 19 electrodes and an SCR device. The obtained neuro-physiological patterns (ERPs, EROs, ERS/ERD and SCRs) were described by the various ontologies of the Neuro-physiological Pattern Domain. This semantic description facilitated the use of semantic queries and rules dealing with the specific study. The aforementioned paradigms result in knowledge retrieval by means of specific queries. Queries may search for studies relating the P300 ERP component during emotional processing with the delta wave activity. Similar queries may involve other neuroscience fields such as memory relating tasks reporting their findings regarding theta oscillations reported for specific brain structures. The semantic rules derived by the C4.5 algorithm can also be employed in the emotion recognition task. Figure 2 illustrates the decision tree representation and its SWRL semantic description.

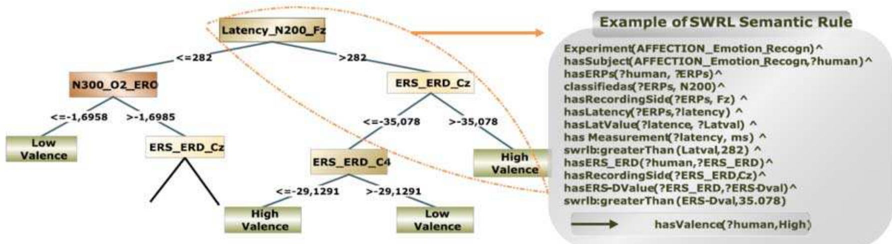

Figure 2. Part of the decision tree (C4.5) used to obtain the SWRL semantic rules for valence discrimination

4. Conclusion

In this paper an ontological framework was proposed envisaged for the semantic description of neuroscience studies and patterns to facilitate knowledge representation, knowledge retrieval, knowledge sharing and knowledge discovery in neuroscience field. The broader scope of this work is to design and implement an ontology-based system to support cross-laboratory, cross-paradigm, and cross-modal integration of neuroscience data and studies as demonstrated in the aforementioned emotional related example. It is clear that much work is needed from the medical informatics research community, and not only, for a proper, "medically semantic" web that will allow for easy and transparent medical queries, as well as, seamlessly integrated healthcare applications. Much of the EU and other funding bodies attention for instance, call for various proposals towards semantic web services, personalised healthcare systems etc. The NIF project [18] is a first attempt along relatively similar lines. This approach is in line with such developments and aims to merge different approaches in order to aim for a future improvement of healthcare quality. Although much of the aimed added value of the presented herein framework will have to be properly evaluated before claiming success, the importance of such approaches cannot be underestimated.

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