Computational Neuroscience
Challenges and Implications for Brazilian Education

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Abstract: Understanding the core function of the brain is one the major challenges of our times. In the areas of neuroscience and education, several new studies try to correlate the learning difficulties faced by children and youth with behavioral and social problems. This work aims to present the challenges and opportunities of computational neuroscience research, with the aim of detecting people with learning disorders. We present a line of investigation based on the key areas: neuroscience, cognitive sciences and computer science, which considers young people between nine and eighteen years of age, with or without a learning disorder. The adoption of neural networks reveals consistency in dealing with pattern recognition problems and they are shown to be effective for early detection in patients with these disorders. We argue that computational neuroscience can be used for identifying and analyzing young Brazilian people with several cognitive disorders.

1 INTRODUCTION

Understanding brain function remains one of the major challenges in the scientific community for the twenty-first century (Abbot 2013). Research on the subject has been growing exponentially since the 1960s. Neuroscience is a research field that has also been growing significantly, beginning from the 1980s (Figure 1). Neuroscience aims to study and analyze the central nervous system (CNS) of humans and animals, their functions, particular format, physiology, and injuries or pathologies. This area has achieved important advances that have been responsible for positive effects on the quality of life of patients suffering from, for example, multiple sclerosis, Alzheimer's disease, Parkinson's disease, and other diseases related to the CNS (Lent 2001). However, despite extensive investment in the area, much remains to be done, especially in relation to understanding the binding mechanisms between brain structures and functions at a microscopic level for cognitive and behavioral processes (Markram 2013).

In the scientific area, the early 90s was announced as the "decade of the brain". This denomination originated in the U.S.A. and sought to encourage the identification of normal neuropsycobiological processes and related disorders. Thus, together with significant advances in computer science and the spread of the Internet, the area of computational neuroscience flourished (Schwartz 1990). Since then, works have been developed and new strategies have been sought for the development of realistic mathematical and computer models to simulate the brain.

Most recently in April 2013, major investigative projects the *BRAIN Initiative* (NIH 2014) and the *Human Brain Project* (HBP 2014) were presented again, in the U.S.A. and Europe, respectively. These initiatives presented demands that propose to revolutionize the understanding of the functioning of the mysteries of the human brain. Thus, in order to

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accelerate the development of new technologies that will allow researchers and scientists to obtain dynamic images of the brain in action, showing how brain cells and complex neural circuits interact at the speed of thought, thereby expanding knowledge about how we think, learn, and remember.

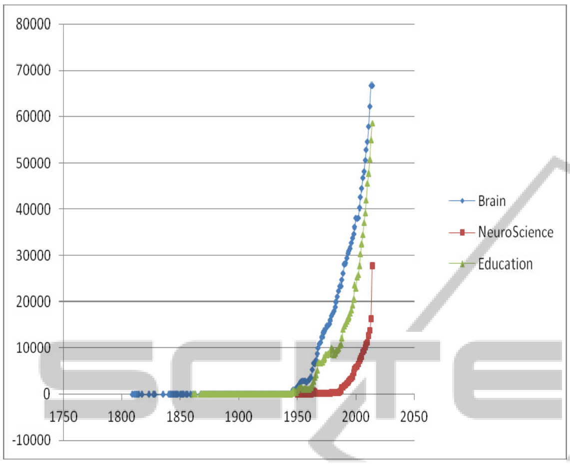

Figure 1: Quantitative comparison of articles, published in the PubMed database, that include the terms "brain", "education" and "neuroscience" in the title (January, 2015). (Y-axis: Number of published articles X-axis: Year of publication).

The structure to accomplish the *BRAIN Initiative* includes private companies, research centers, and government agencies, as well as a wide range of experts ranging from physicians, neuroscientists, nanoscientists to engineers and computer scientists as well. The last ones working in the fields of artificial intelligence, databases, high performance computing, big data, e-science, games, robotics, sensors, and social networks, among other (Zhong 2012; NIH 2014; HBP 2014).

In Brazil, significant efforts developed by neuroscientists is recorded for the development of knowledge related to the brain and the "Brazilian Brain Industry". Among the various research centers, we can mention the work developed at the International Neuroscience Institute of Natal Edmond and Lily Safra (IINN-ELS) and the Institute of Biomedical Sciences of UFRJ (ICB-UFRJ). Despite these great efforts and the synergy between computational neuroscience and education still needs to go further. Novel studies that correlate the learning disorders faced by children and young people with various computational techniques ought to be developed. Such disorders have deep social relevance in the educational area, for example, where they may have an effect on truancy, functional illiteracy, and repeated failures, as well as the self-esteem of individuals.

The goal of this paper is to report research directions and highlight the challenges related to the adoption of computational neuroscience to enhance the quality Brazilian education. This work also presents our ongoing computational approaches related to the classification of patients with dyslexia, one of the learning disorders that has aroused interest among Brazilian researchers, health professionals, and schools teachers.

This paper is organized as follows. Section 2 persent the current challenges of Computational neuroscience. Section 3 present the researche opportunities. Section 4 present the researches that are being conducted by our research team. Finally, section 5 concludes the paper.

2 CHALLENGES

Computational neuroscience can be used as a toolset for building intelligent computational systems that are capable of processing and analyzing large volumes of (structured and semi-structured) educational data. Computational neuroscience can be used to elaborate educational games, or even developing mobile applications targeted at diagnostic support and tracking of learning disorders (Zavaleta et al., 2012).

Computational neuroscience is essentially interdisciplinary and rests on key three pillars: *neuroscience* (the areas of medicine and biological sciences); *cognitive science* (psychology); and

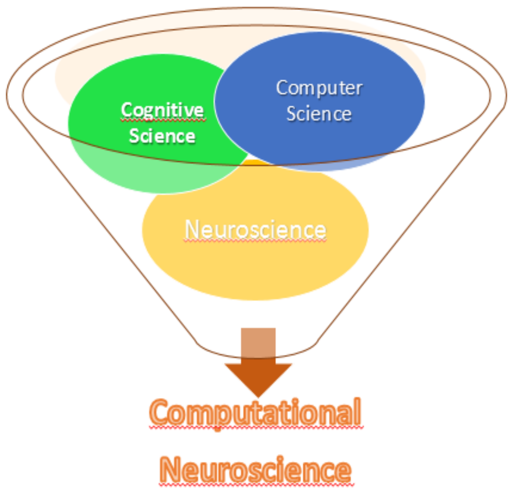

Figure 2: Three pillars in computational neuroscience and prospects for technological investigations supported by computer science.

computer science (artificial intelligence, databases, e-science, provenance, big data, high performance computing (HPC), cloud computing, internet of things, etc.) (Figure 2). However, one of the major difficulties of computational neuroscience is to model (mathematically and computationally) a learning disorder, identify the most relevant variables and data, transcribe them for technological solutions, and determine if the computational results are significant and valid according to medical, ethical, and educational aspects.

To achieve a technological level compatible with the multifaceted demands of brain studies in the twenty-first century, we must consider the structure of a research agenda that is focused on *new models* and the incorporation of (*data intensive*) *computational techniques traditional to e-science* (Hey et al. 2009) for the development of applications in computational neuroscience. In this case, it is possible to advance in the following areas:

a) Development of intelligent and predictive systems based on artificial intelligence techniques (Macário Costa et al. 2007, 2008, 2009, 2010, 2011, 2013; Zavaleta et al. 2012) capable of handling large volumes of data;

b) Use of distributed computational environ-ments for high-performance processing of intelligent systems, to support *in silico* simulations and experiments based on scientific workflows (Deelman et al. 2009) of simulations of brain models (Abbot 2013; Kubilius, 2014; NIH 2014; HBP 2014).

c) Adoption of management techniques for large volumes of semi-structured biological data and processing typically used for big data (Davison 2010; Berman 2011; Abbott 2013) — computational neuroscience projects are gravitating towards mapping increasingly larger and more complex brain models that use sensors and data in different formats (Zhong et al. 2011; Zhong 2012);

d) Incorporation of provenance descriptors (Cruz et al. 2009, 2012) and data management and techniques to increase the reproducibility and reliability of studies in computational neuroscience (Chen, Zhong, and Liang 2012; Ciccarese et al. 2013) — these activities tend to be conducted by interdisciplinary research teams that are geographically and temporally dispersed (Chen and Zhong 2013);

The knowledge acquired in the area of neuroscience can be associated with novel tools and computational techniques for improving the opportunities to act on learning disorders.

Dyslexia can be characterized by a failure in the acquisition and/or development of scholastic skills. Dyslexia is a learning disorder that affects 3–7% of the school-age population, and it highlights other disorders including severe delays in reading, writing, and spelling, as well as inversion of symbols. This work is focused in dyslexia due to its singularity and limited nature of the phonological deficit (Shaywitz and Shaywitz 1999; Mousinho 2003). Detailed understanding of the correlations between genetic variations, brain dysfunction, and cognitive difficulties is a great challenge in dyslexia research (Giraud and Ramus 2013) such investigation require large computing efforts due to the large amount of data. Currently, an evaluation of a dyslexic individual takes on average two months until the establishment of a diagnosis by a qualified team. Usually, the students referred to the health service do not have dyslexia, but learning problems of different orders. Here it we state that the establishment of new tracking systems, based on computational neuroscience, will possibly reduce the queues and speed up access to diagnosis, thus offering chances of intervention to more children and young people in a short time period, in a more opportune, efficient, and socially just manner.

3 IMPLICATIONS

Investigations directed at the tracking of children and young people with dyslexia at school age will contribute to establishing evaluations related to the timely identification and referral of people with learning disorders in schools, whether public or private.

Mousinho (2011) states that it is almost a routine situation to find students with reading problems. In most schools, classes are composed of children who are more or less adept at reading. Among the less skilled children, there are still those that stand out. Despite their efforts, reading tasks for these children becomes a laborious and even painful activity. The effort put into this action is so big that it may even hinder the pleasure of reading.

Children with more impaired reading tend to increase the gap between themselves and their peers, which may increase the incidence of undesirable consequences such as the loss of enjoyment of reading, low performance in other disciplines that depend on reading, and the development of low self-esteem by the child (Mousinho 2011).

Early identification of children with reading and learning difficulties has become a priority due to the possibility of eliminating or reducing the detriment to the children's scholastic and social progress. Thus, the adoption of disruptive computational strategies based on computational neuroscience can make all the difference in this identification.

One of the most common computational strategies of computational neuroscience is the use of neural networks. Neural networks are mathematical models that simulate biological neural structures and have computing ability acquired through learning and generalization. We believe that the biggest challenge is in gathering all the different kinds of information (variables) into databases and developing new mechanisms for analysis and detection of dyslexic patients.

Therefore, our research efforts were developed in order to detect which children and adolescents were at risk of dyslexia. The prior versions of the intelligent system developed by Macário Costa et al. (2007, 2008, 2009, 2010, 2011, 2013) is expanding its database in order to further consolidate the accuracy of the algorithms. The algorithms were used to extract the useful patterns from the data collected during interviews done with the person responsible for the child who is enrolled in the school, in the search for a desired pattern to identify individuals who have the learning difficulties.

In order to support the diagnosis of specific learning disorders, Macário Costa et al. (2011, 2012, 2013) resent the implementation of a multi-layer perceptron neural network to probabilistically classify youth and adult patients with dyslexia.

4 RESEARCH GOALS

This paper aims to discuss the challenges and open opportunities to develop novel computational solutions that can contribute as support tools for specialists to detect and diagnose, in advance, individuals with learning disorders in our country. The computational solutions we highlight can be applied directly by teachers in elementary and primary schools. We advocate that there is a need to establish partnerships with public and private institutions, governments, and research groups, that can cooperate and provide computational infrastructure capable of storing and processing, in a distributed manner, large amounts of semi-structured data. Besides, it is also important to offer a commitment to involve their teams in the schools in order to track the individuals who have learning difficulties and/or are at risk of dyslexia or other learning disorders.

The goals of our research is inherently multidisciplinary and should be performed by people with different skills (Macário Costa et al, 2014). It is divided into three phases. The first phase, which has already been performed, consisted of outlining the problem and designing the tools and the neural networks, followed by the construction of the intelligent system and its database, and then performing the testing and evaluation of the models.

The second phase, which is in progress, consists of the survey of new demands necessary for the scalability of the solution, enabling it to incorporate the new technological artifacts (discussed above) that can process large volumes of data in high-performance distributed environments. In this phase there is also the mapping of new collaborators and schools. Without a combination of technologies, we cannot answer the basic questions such as: How do we detect — at an early stage, at a low operating cost, and at high effectiveness — young people at risk of dyslexia or other learning disorders? In a country like Brazil, with its continental dimensions and its historical social inequalities, obtaining answers to questions of this nature could be a strategic advantage for the country's future.

The third and final phase is crucial for the project's success. It will be more widespread and will be operational. It will be directed toward the massive and early detection approaches in the school environment in order to detect the children with reading and learning difficulties. This phase requires accurate, reliable, and quick analysis and processing of data to assist in the medical diagnosis, and to establish early referral of these individuals to specialists.

5 CONCLUSIONS

This research allowed us to develop an intelligent computational system, using artificial intelligence techniques for the detection of individuals between 9 and 18 years of age who have learning difficulties (dyslexia). The intelligent computational system is composed of several modules, some are completed and the others are being developed.

The neural network (NN) module allowed the development of a method to support the process for identifying people and children with dyslexia and other learning difficulties. A database was developed for the collection of data used by the NN module. This module has been completed and the others are in the development and testing phase.

The individuals identified in the NN module pass to the Response to Intervention (RTI) pyramidal module which consists of three layers of evidence-based interventions for promoting the social, emotional, and behavioral development of children. Each layer uses fuzzy logic to assign degrees of learning difficulty to the individuals and determine the most appropriate computational intervention for each layer of the RTI model. Each layer of the RTI model will consist of a set of computational intervention methodologies (e.g., games) activated by the degree of difficulty for each individual.

The proposed approach can be used innovatively as a support tool for the diagnosis of dyslexia and other learning difficulties. Further details and detailed descriptions can be found at our previous work (Macário Costa et al., 2014).

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