WCCI 2014 Tutorial Lecture

COMPUTATIONAL INTELLIGENCE APPROACHES TO IDENTIFICATION AND EARLY DIAGNOSIS OF MEMORY'S DISEASE

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ABSTRACT OF THE TUTORIAL

One of the major societal challenges for future decades is the possibility of understanding the process of normal ageing and wellness, in contrast to memory/cognitive pathological dysfunctions which give rise to dementias. Since brain diseases seriously affect people's lives and have a strong impact on developed nations' economy, to explore the changes in brain's neural networks at the basis of functional impairment it is a relevant scientific objective. These diseases can disrupt neural activities at various scales such synapses, neuronal populations, local circuits in specific brain regions, and even higher order neural networks. Much evidence from neuroimaging and neurophysiological studies support the idea that a network-based approach is critical to explain and predict brain alterations.

Actually, the diagnosis of pathologies, like the high-rate prevalence growing Alzheimer's Disease (AD) or the rare neurological disorder known as Creutzfeldt-Jakob disease (CJD), is definitely made post-mortem through autopsy. However, the diseases often imply a very long evolution which already starts decades before it is diagnosed. In order to recognize the onset of the disease, and thus to anticipate the treatment, it is needed to understand how normal ageing brain (in healthy control groups) differs from the brain of people which is going to become affected from such forms of dementias.

The status of Mild Cognitive Impairment (MCI) is mainly characterized by some kinds of memory impairment or cognitive dysfunctions that are insufficient to meet the accepted criteria for the diagnosis of dementia. However, the annual conversion rate from normality to dementia ranges between 0.5% and 5%, whereas that from MCI to AD is between 6% and 20%. It is an open issue with significant clinical implications whether or not is possible to predict the conversion from MCI to AD and thus to consider it as a prodromal stage of AD. If so, some actions could be taken in order to delay or mitigate somehow the disease through novel drugs, dietary requirements or specific cognitive exercise. The potentiality of approaches derived from *Computational Intelligence*, *Neural Network* models simulations, and *Complex Networks* analysis could help in anticipating the diagnosis of AD or other forms of dementias: this would have a great scientific and clinical impact thus growing the relevance of CI community.

Several diagnostics are available to analyze the pathological brain, namely, SPECT, fMRI, DTI, BOLD: most late diagnoses are made by processing such data. For example, atrophy of hippocampus and thalamus are detected at different stages of AD, and CI tools are explored to improve those kind of diagnostics. However, an early diagnosis at a group level (i.e., screening) should be noninvasive, cheap, and easily repeatable. This motivates the study of EEG signals. For example, it has been shown that some dementias' features reflect on the EEG frequency spectrum at different brain rhythms. Real-life applications motivate approaches that go beyond traditional linear methods. In particular, non-linear analysis of the EEG changes may add insight into the abnormal dynamics of cortical neural networks.

In this tutorial, it will be shown how both standard and innovative computational intelligence techniques are indeed of great help in facing the problems of defining novel markers of dementias, in extracting non

trivial features from EEG databases, in improving the diagnosing based on other markers (also extracted from different diagnostic systems), and in differential diagnosis.
The topic presented are mainly based on recent researches carried out by the author and his co-workers at the NeuroLab of the University Mediterranea, as well as on networking with several other research and clinical centers.
These directions of research include new ways of using well known approaches, as well as the introduction of new formulations of the early diagnosis problem. This tutorial will review standard approaches in the literature, and then discuss several possible 'non-standard' formulations.
The tutorial consists of four parts:

(1) *Motivation for Computational Intelligence approaches*. We provide historical and application-driven motivations for developing new approaches to the diagnosis of dementias under the general conceptual framework of Computational Intelligence. Then we present state-of-the-art formulations, and critically review the assumptions underlying such formulations. Relaxing some of these assumptions leads to several 'non-standard' formulations as discussed below.
(2) *CI techniques for EEG-based diagnosis*. These include: the use of ICA and AWICA for automatic EEG cleaning from artefacts; the use of various entropy formulations for measuring signal complexity (Sample Entropy, Permutation Entropy, Lempel-Ziv Complexity); the use of Support Vector Machines (SVM) for classification, identification and markers fusion from different diagnostics. We describe these formulations, and several recent applications studies comparing traditional and CI-based performance.
(3) *Application-driven novel formulations*. We outline a general framework for mapping application requirements onto a CI-based problem formulation, and then provide examples of such new application-driven formulations. Such examples range from the use of Empirical Mode Decomposition to the Complex Network Theory. Graph-theoretical analysis provides indeed a mathematical and conceptual framework for studying the brain as a whole network thus capturing various aspects of global topological organization as well as local contributions of different regions to network function (i.e., small-worldness). Finally, the Compressive Sensing technique is also proposed to discriminate among groups based on different EEG compressibility.
(4) *Multiscale and Multivariate EEG processing*. Commonly, traditional CI formulations assume that the EEG channel are processed as a single time series. The proposed methods will include and critique the possibility of using novel approaches to analyze EEG at multiple time and space scales. This approach is particularly suitable for electrophysiological time-series: it will be shown that the AD brain is characterized by a loss of connections at multiple scales, and a reduced efficiency in terms of both energy and cognitive cortical circuits involvement. The concept of Multivariate Multiscale Permutation Entropy will be proposed as a novel formulation for improving the prediction performance. The Complex Network approach will be introduced and critically discussed by suggesting novel approaches to monitor the progression of the diseases.

Several MatLab-based exercises will be proposed by making available both the codes and the data for self-reproduction of examples by the students. Some short EEG data for AD patients, MCI subjects, CJD patients and Healthy Controls will be given to the participants and put on a suitable page of the NeuroLab (or WCCI) website if the proposal will be approved.

DURATION

The tutorial will last 2 hours.

INTENDED AUDIENCE

Researchers and practitioners interested in understanding and using new CI formulations motivated by practical EEG recordings requirements, rather than standard formulations motivated by medical-based clinical approaches. The timeliness of this tutorial lecture is largely justified from the huge number of papers recently published on the subject and the research funds invested in those researches all over the world.

ABOUT THE INSTRUCTOR

Francesco Carlo Morabito is a Full Professor of Electrical Engineering at the University Mediterranea of Reggio Calabria. At the University Mediterranea, he served as President of the Council of Electronic Engineering (1998-2000), member of the Evaluation Committee (2000-2001) and as Dean of the Faculty of Engineering (2001-2008). Visiting Researcher at the Max-Planck Institute fuer Plasma-Physics (Munich) from 1993 to 1999, he taught at the 3rd Cycle (Ph.D.) level course on "Intelligent Interfaces and Systems" at the EPFL (Swiss Polytechnic Institute of Lausanne) in 1999.

Member of IEEE (1989), Senior Member (2000), member of INNS (1992) and Senior Member (2008). He served as Governor of INNS from 2000 to 2012.

Since 2008 he serves as President of the Italian Society of Neural Networks (SIREN). Foreign Member of Spanish Academy of Doctors (2004), and recipient of the Gold Medal "Henry Coanda" of the Rumanian Academy of Sciences for his research on Fuzzy Systems and Neural Networks (2003).

He refereed both international and national research projects (Swiss National Science Foundation, NATO, ASI, MIUR), and was responsible for national and international research projects.

He serves as Associate Editor for various intl. journals (Neural Networks, Intl. Journal Chaos T&A, IJ Computer, Systems and Signals, Intl J. of Information Acquisition, Applied Comp. Int. and Soft Computing, Intl. J. of Biomedical Sciences, Recent Patents in Computer Science, Fuzzy Economy Review, and Renewable Energy). He recently coedited a special issue of Neural Networks on Brain Neuromorphic Engineering (2013) and a special issue of IEEE Sensors on the tutorial topics (2013).

Author or co-author of more than 280 scientific peer-reviewed papers in journals and conference proceedings, and book chapters. He holds 3 patents and edited 10 books.

OTHER CONSIDERATIONS

The proposed tutorial is also based on two invited talks (on the subject of *Complexity Measures for Biosignals Analysis*) given by the instructor at KAIST, Daejeon, South Korea, and ETH-INI Zurich, Switzerland. The instructor has gained relevant experience in the organization of Tutorials: in particular, he was the Chair of the Tutorial Program at the IJCNN 1999 (Washington, D.C., USA), 2001 (Washington, D.C., USA), 2003 (Portland, Oregon, USA), 2005 (Montreal, Canada) and he delivered a Tutorial Lecture at the IJCNN 1999, Washington, D.C., USA.

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