Notice of the Final Oral Examination
for the Degree of Doctor of Philosophy

of

BABAK KESHAVARZ HEDAYATI

MSc (Iran University of Science and Technology, 2010)
BSc (Khajeh Nasireddin Toosi University of Technology, 2007)

“Studies on Applications of Neural Networks in Modeling Sparse Datasets and in the Analysis of Dynamics of CA3 in Hippocampus”

Department of Electrical and Computer Engineering

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9:00 A.M.
Engineering and Computer Science Building
Room 468

Supervisory Committee:
Dr. Nikitas Dimopoulos, Department of Electrical and Computer Engineering, University of Victoria (Supervisor)
Dr. Kin Li, Department of Electrical and Computer Engineering, UVic (Member)
Dr. Arif Babul, Department of Physics and Astronomy, UVic (Outside Member)

External Examiner:
Dr. Emil Petriu, Electrical Engineering and Computer Science, University of Ottawa

Chair of Oral Examination:
Dr. Lynne Siemens, School of Public Administration, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies
Abstract

Neural networks are an important tool in the field of data science as well as in the study of the very structures they were inspired from i.e. the human nervous system. In this thesis, we studied the application of neural networks in data modeling as well as their role in studying the properties of various structures in the nervous system. This thesis has two foci: one relates to developing methods that help improve generalization in data models and the other is to study the possible effects of the structure on the function.

As the first focus of this thesis, we proposed a set of heuristics that improve the generalization capability of the neural network models in regression and classification problems. To do so, we explored applying appriori information in the form of regularization of the behavior of the models. We used smoothness and self-consistency as the two regularized attributes that were enforced on the behavior of the neural networks in our model. We used our proposed heuristics to improve the performance neural network ensembles in regression problems (more specifically in quantitative structure activity relationship (QSAR) modeling problems). We demonstrated that these heuristics result in significant improvements in the performance of the models we used. In addition, we developed an anomaly detection method to identify and exclude the outliers among unknown cases presented to the model. This was to ensure that the data model only made a prediction about the outcome of the unknown cases that were within its domain of applicability. This filtering resulted in further improvement of the performance of the model in our experiments.

Furthermore, and through some modifications, we extended the application of our proposed heuristics to classification problems. We evaluated the performance of the resulting classification models over several datasets and demonstrated that the regularizations we employed in our heuristics, had a positive effect on the performance of the data model across various classification problems as well.

In the second part of this thesis, we focused on studying the relationship between the structure and the functionality in the nervous system. More specifically, whether or not the structure implies functionality. In studying these possible effects, we elected to study CA3b in Hippocampus. For this reason, we used current related literature to derive a physiologically plausible model of CA3b. And to make our proposed model as close as possible to its
counterpart in the nervous system, we used large scale neural simulations, in excess of 45,000 neurons, in our experiments. We used the collective firings of all the neurons in our proposed structure to produce a time series signal. We considered this time-series signal which is a way to demonstrate the overall output of the structure should it be monitored by an EEG probe as the output of the structure. In our simulations, the structure produced and maintained a low frequency rhythm. We believe that this rhythm is similar to the Theta rhythm which occurs naturally in CA3b.

We used the fundamental frequency of this rhythm in our experiments to quantify the effects of modifications in the structure. That is, we modified various properties of our CA3b and measures the changes in the fundamental frequency of the signal.

We conducted various experiments on the structural properties (the length of axons of the neurons, the density of connections around the neurons, etc.) of the simulated CA3b structure. Our results show that the structure was very resilient to such modifications.

Finally, we studied the effects of lesions in such a resilient structure. For these experiments, we introduced two types of lesions: many lesions of small radius and a few lesions with large radii. We then increased the severity of these lesions by increasing the number of lesions in the case of former and increasing the radius of lesions in the case of the latter.

Our results showed that many small lesions in the structure have a more pronounced effect on the fundamental frequency compared to the few lesions with large radii.