Abstract

This habilitation thesis presents the most important scientific, professional, and academic achievements of its author, starting from May 29th, 2015, when the author defended his PhD thesis entitled “Learning algorithms for Clifford neural networks”, at the Politehnica University of Timișoara.

In this period, the author elaborated 29 papers, all as first author, out of which 6 were journal papers, published in high impact academic journals, and 23 were conference papers, published at premiere conferences in the field of artificial intelligence, more precisely of neural networks. The author was also the director of two research grants won by competition.

The author began his academic career in October 2015 as a Teaching Assistant, then promoted to Assistant Professor in October 2016, and from October 2019, he is an Associate Professor at the Department of Computers and Information Technology, at the Politehnica University of Timișoara. He updated the course and/or the laboratory for 4 courses, and introduced 4 new courses at the Master of Machine Learning, for which he is the program coordinator. He was also the coordinator for over 70 Bachelor’s theses, over 20 Master’s theses, and is a member of the guidance commission for 7 doctoral students.

All these achievements are presented in detail in Chapter 1 of the thesis.

The scientific research of the author continued in the domain of complex- and hypercomplex-valued neural networks, extending from the feedforward neural networks discussed in the PhD thesis, to more general neural networks models belonging to the deep learning paradigm, like convolutional neural networks, stacked denoising autoencoders, deep belief networks, deep Boltzmann machines, and especially recurrent neural networks, more specifically Hopfield networks and bidirectional associative memories, for which different dynamic properties were studied.

Chapter 2 presents a somewhat direct continuation of the work done in the PhD thesis. It presents learning algorithms for quaternion-valued neural networks, but deduced in a different way than that in the PhD thesis of the author, using the recently introduced $\mathbb{HR}$ calculus. The algorithms discussed are: enhanced gradient descent algorithms, conjugate gradient algorithms, scaled conjugate gradient method, quasi-Newton learning methods, and Levenberg-Marquardt learning algorithm. The chapter summarizes 5 conference papers and 1 journal paper of the author.

Then, Chapter 3 is dedicated to summarizing 6 conference papers of the author, and aims to extend deep learning-specific algorithms to the complex domain. As such, complex-valued convolutional neural networks are introduced, a variant based on the Fourier transform, and a hybrid real–complex-valued variant of these networks. The classical deep learning models stacked denoising autoencoders, deep belief networks, and deep Boltzmann machines were extended to the complex-valued domain next.

Chapters 4 and 5 are each based on 1 journal paper of the author, and mark the transition to the study of dynamic properties for complex- and hypercomplex-valued neural networks (more precisely, quaternion-valued neural networks in this case). The analysis of the dynamic prop-

erties of neural networks is a research field in its own right, with hundreds of papers appearing each year in this domain. The extension to multidimensional neural networks of this field is rather recent, and has gained increasing interest in the last few years.

Dynamic properties of octonion-valued neural networks are discussed in Chapter 6, which is based on 5 conference papers and 2 journal papers of the author. The domain of octonion-valued neural networks were introduced by the author in a paper summarized in the first section of Chapter 6. Then, the author introduced Hopfield networks and bidirectional associative memories with octonion values, which are the subject of the next two sections. The asymptotic and exponential stability properties of octonion-valued Hopfield neural networks with different types of delays are discussed in the rest of the chapter.

Matrix-valued neural networks were also introduced by the author in his PhD thesis. Chapter 7 presents the Hopfield and bidirectional associative memory variants of these networks, for which the asymptotic and exponential stability and dissipativity properties were analyzed. The contents of the chapter is based on 7 conference papers and 1 journal paper of the author. A special type of matrix-valued neural networks, Lie algebra-valued neural networks, were also first formulated by the author. As such, the last section of Chapter 7 introduces Hopfield networks and bidirectional associative memories with Lie algebraic values.

Lastly, the thesis ends with Chapter 8, which sketches the scientific, professional, and academic future work plans of the author.