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Akira Hirose

Complex-Valued Neural Networks

Second Edition

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Preface to the Second Edition

Five years have passed since the First Edition of this Book was published. Fortunately it obtained a large readership, and seems to have made a humble contribution to the development of the complex-valued neural-network research. The author is extremely grateful to the readers for their explicit or implicit insightful comments and continuous support. It is my great pleasure to have the occasion to publish the Second Edition.

During this period, the research on complex-valued neural networks expands largely in both the quality and the quantity. There have been many special sessions in representative conferences which cover not only mathematical sciences but also electrical and electronic engineering such as the International Joint Conference on Neural Networks (IJCNN) sponsored by IEEE Computational Intelligence Society (IEEE CIS) and International Neural Network Society (INNS), including the biyearly held World Congress on Computational Intelligence (WCCI), the International Conference on Neural Information Processing (ICONIP) promoted by Asia-Pacific Neural Network Assembly (APNNA) organized by Asia-Pacific countries' neural network societies such as Japanese Neural Network Society (JNNS), and the International Conferece on Artificial Neural Networks (ICANN) organized by the European Neural Network Society (ENNS). A project named "Practical Applications of Complex-Valued Neural Networks" has also been organized as one of the Nation-wide Cooperative Research Projects in Research Institute of Electrical Communication (RIEC), Tohoku University, in 2009 to accelerate application-oriented research in technology and society. A worldwide network, namely, the Task Force on Complex-Valued Neural Networks, has also been inaugurated in the Institute of Electrical and Electronics Engineers (IEEE) Computational Intelligence Society (CIS) Neural Network Technical Committee (NNTC) with more than 40 active members.

Recent progress is summarized as follows. The application fields spread more and more in electromagnetic-wave, lightwave and ultrasonic-wave engineering areas such as earth and environmental observation with satellite/airborne radar systems, security imaging at airports, railway stations

and other public transportation, and medical diagnosis and monitoring utilizing coherent wave phenomena. Other growing fields include adaptive image processing in frequency domain and time-sequential signal processing widely. Theories are going to extend from complex and quaternion networks to more general frameworks based on Clifford algebra.

This Second Edition is an enlarged and revised book featuring mainly the following two points. The first is the inclusion of recent trends in the overview in Section 3.7 (research history) as well as in respective chapter citation in Part II (applications), resulting in almost doubled number of references. The parametron invented in 1954 is also referred to with discussion on analogy and disparity. The second point is the addition of argument on the advantages of the complex-valued neural networks in Sections 3.1 (history of complex number), 3.2 (degree of freedom and circularity in learning), 3.4 (metric in complex domain) and some other sections to enhance the difference from real-valued neural networks.

The author is very much obliged to Prof. Janusz Kacprzyk, Editor-in-Chief, Studies in Computational Intelligence, and Dr. Thomas Ditzinger, Engineering Editor, Springer-Verlag, for their continuous help in publication. I express my sincere thanks also to Mr. Kosuke Hirase and Mr. Nobuhiko Tajima, Executive Editors, Saiensu-sha, for their kind permission and promotion.

Tokyo, Japan Akira Hirose
October 2011

Preface to the English First Edition

The original Japanese edition of this book, published by Saiensu-sha, Japan, in March 2004, has fortunately acquired a favorable reputation. I am grateful to the readers for their kind feedbacks, many of which are included in this edition. I hope this English publication attracts readers in wider areas, and evokes valuable feedbacks furthermore.

In the months after the Japanese publication, researches on the complex-valued neural networks have kept evolution in respective directions. There are some plans of special sessions in international conferences and special issues in journals. The bibliography has been slightly modified to include the special sessions and latest journal publications. On the other hand, references written in Japanese on domestic circumstances have been omitted.

Besides, Fig.1.1 has been added, and Fig.2.1 has been modified, which are related to the *Special Issue on Complex-Valued Neural Networks*, The Journal of the IEICE, 87 (6), June 2004 (in Japanese), so that even readers not having glanced the issue can obtain clear concepts. With these modifications, I expect a higher appeal in this English edition.

I am very much obliged to Dr. Thomas Ditzinger, Engineering Editor, Springer-Verlag, for his continuous help in publication.

Tokyo, Japan
April 2006

Akira Hirose

Preface to the Japanese First Edition

The studies on complex-valued neural networks have recently been evolving in various directions. The pioneering areas include electromagnetic-wave and lightwave sensing and imaging, independent component analysis in blind separation, blur restoration in image processing, and so on. Developing applications involve adaptive quantum devices, quantum computation, social systems related to periodicity and oscillation, and so forth.

This book is the first one to describe systematically the complex-valued neural networks. It is recommendable for researchers, graduate students, and undergraduate students in, for example, *electrical and electronic engineering, informatics, control engineering, mechanics, robotics, and bioengineering*. This book is useful for those who begin to study, for instance, adaptive signal processing for highly functional sensing and imaging, control in unknown and changing environment, brain-like information processing, robotics inspired by human neural systems, and interdisciplinary studies to realize comfortable society. It is also helpful to those who carry out *research and development regarding new products and services at companies*. The author wrote this book hoping in particular that the book provides them meaningful hints to make good use of neural networks in fully practical applications.

The first multiauthor book focusing on the complex-valued neural networks is "Complex-Valued Neural Networks: Theories and Applications" published by World Scientific Publishing Co. (October 2003), in which researchers most active in this field reconstruct and present their pioneering works. Besides, a foreword describes the relation of the complex-valued networks with other fields and the real world. In addition, an introductory chapter outlines this widely expanding field listing theoretical and application aspects.

On the other hand, this book, "Complex-Valued Neural Networks," describes the field systematically by a single researcher. The book emphasizes basic ideas and ways of thinking. Why do we need to consider neural networks that deal with complex numbers? What advantages do the complex-valued neural networks have? What is the origin of the advantages? In what areas do they develop principal applications? This book answers these questions

by describing details and examples, which will inspire many readers with new ideas. It may not be completely comprehensive. Instead, the author decided to make effort not to include all things relevant to this field, but to describe vividly this extensively developing field. Therefore, the fields, where the strong points of the complex-valued neural networks will potentially play important roles, extend further beyond those explained in this book.

The book consists of two parts. Part I describes basic concepts, ideas and fundamentals, while Part II presents application examples and illustrates how to use the networks in specific situations. In Part I, an application example is presented in Chapter 1, so that the readers grasp the rough idea of the complex-valued neural networks. Chapter 2 provides briefly the viewpoint of the artificial neural networks in general in the framework of information processing. Chapter 3 presents basic ideas, overview of applications, and a historic outline. Then, Chapter 4 explains constructions and dynamics of the complex-valued neural networks. In the descriptions, *conventional neural networks are first presented, and then, they are extended into the complex-valued networks. Consequently, the readers are able to understand the contents even if they do not have any knowledge on conventional neural networks.*

Therefore, *the book is recommendable as an introduction not only to the complex-valued networks, but also widely to the artificial neural networks.* The manner of description in this book places stress on the intuitional understanding of actual dynamics, practical advantages, and effective applications, rather than mathematical rigorousness. If the readers require formal mathematics further more, please refer to literature presented in each chapter.

The fields relevant to the complex-valued neural networks are enormously wide since, from a certain viewpoint, we may regard them as a superset of the conventional networks. The author is afraid that the book may includes serious errors and misunderstanding, on which the readers' corrections and suggestions are heartily welcome. Please note that the imaginary unit $\sqrt{-1}$ is expressed as i or j in accordance with the customs in respective fields.

The application examples presented in Part II have been obtained in the A. Hirose Laboratory, The University of Tokyo, with many graduate and undergraduate students belonging to the Courses in Electrical and Electronic Engineering, Computer Science, Frontier Informatics, and Interdisciplinary Science and Technology. That is, the results in Chapters 5 (land-surface segmentation) and 7 (digital elevation map) have been obtained mainly by Dr. Andriyan Bayu Suksmono, Chapter 6 (landmine visualization radar system) by Mr. Takahiro Hara, Chapters 8 (carrier-frequency-dependent associative memory) and 9 (optical phase equalizer) by Dr. Sotaro Kawata, Chapter 10 (developmental learning) by Mr. Yasufumi Asano and Mr. Toshihiko Hamano, and Chapter 11 (voice synthesis) by Mr. Keiichi Tsuda. The author expresses his sincere thanks to them and all other laboratory members and alumni. The details in the studies are available on the web pages of the Laboratory (http://www.eis.t.u-tokyo.ac.jp/).

The author is grateful also to Mr. Kosuke Hirase at Saiensu-sha, Japan, and Mr. Naoshi Takeda at Suuri-kogaku-sha, Japan, for their great help in publication.

Lastly, the author would like to ask all the readers for their cooperation in this developing field by quoting from the Preface, contributed by Dr. Nobuo Hataoka, in the *Special Issue on "Complex-Valued Neural Networks,"* The Journal of the IEICE, vol.87, No.6 (2004) p.446: "The complex-valued neural networks deal with phase information in addition. They possess remarkable ability in comparison with the conventional networks. However, they have just departed from the starting point." The author would like to make further effort to construct practically useful neural networks by obtaining the cooperation of researchers at large in the world.

Tokyo, Japan Akira Hirose
December 2004

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