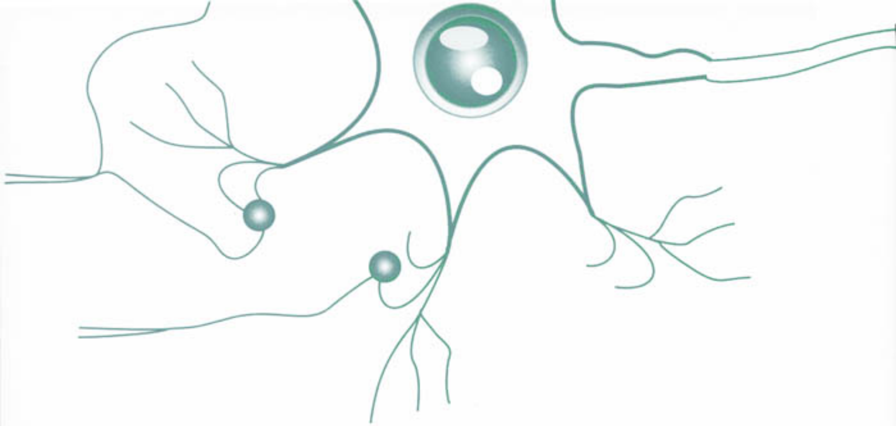
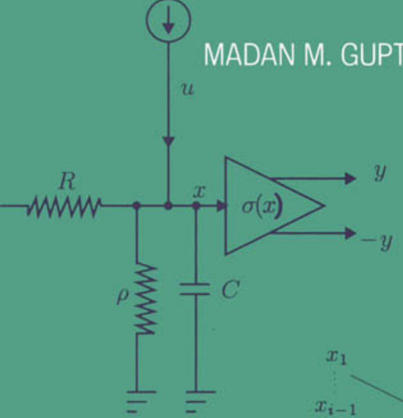


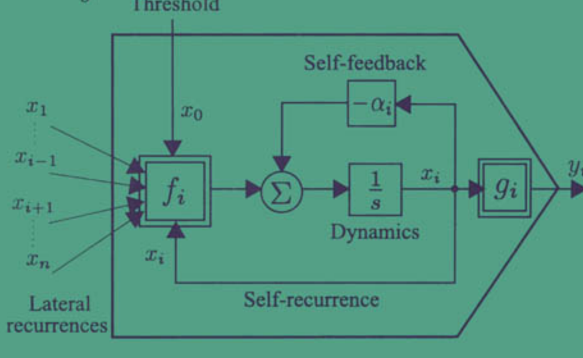
STATIC AND DYNAMIC NEURAL NETWORKS

From Fundamentals to Advanced Theory

MADAN M. GUPTA, LIANG JIN, and NORIYASU HOMMA

Foreword by Lotfi A. Zadeh





Static and Dynamic Neural Networks

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ॐ भूर्भुवः स्वः ।

तत्स वितुर्व रेण्यम ॥

भर्गो देवस्य धीमहि ।

धियो यो नः प्रचोदयात् ॥

॥ ॐ शान्ति शान्ति शान्तिः ॥

OM BHURBHUVAH SVAH !
TATSAVITUR VARENYAM !!
BHARGO DEVASYA DHIMAHI !
DHIYO YO NAH PRACHODAYATH !!
OM SHANTI ! SHANTI !! SHANTIHI !!!

(yajur-36-3, Rig Veda 3-62-10)

We meditate upon the Adorable Brilliance of that Divine Creator.
Who is the Giver of life, Remover of all sufferings, and Bestower of bliss.
We pray to Him to enlighten our minds and make our thoughts clear,
And inspire truth in our perception, process of thinking, and the way of our life.
Om Peace! Peace!! Peace!!!

全能の神への祈り
神は生命を与え　苦しみを取り除き　そして至福を授ける
神よ　我々の心に真実の光を照らし
知覚　思考　人生すべてを真理へと導きたまえ
そして　泰平の安らぎを

We dedicate this book to

Professor Lotfi A. Zadeh
(The father of fuzzy logic and soft computing)

and

Dr. Peter N. Nikiforuk
(Dean Emeritus, College of Engineering),
who jointly inspired the work reported in these pages;

and, also to

The research colleagues and students in this global village,
who have made countless contributions to the developing fields of
neural networks, soft computing and intelligent systems,
and, have inspired the authors to learn, explore and thrive in these areas.

Also, to

Suman Gupta, Shan Song, and Hideko Homma,
who have created a synergism in our homes
for quenching our thirst for learning more and more.

Madan M. Gupta
Liang Jin
Noriyasu Homma

Contents

PART III DYNAMIC NEURAL NETWORKS

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Foreword

It is very hard to write a book that qualifies to be viewed as a significant addition to the voluminous literature on neural network theory and its applications. Drs. Gupta, Jin, and Homma have succeeded in accomplishing this feat. They have authored a treatise that is superlative in all respects and links neural network theory to fuzzy set theory and fuzzy logic.

Although my work has not been in the mainstream of neural network theory and its applications, I have always been a close observer, going back to the pioneering papers of McCulloch and Pitts, and the work of Frank Rosenblatt. I had the privilege of knowing these major figures and was fascinated by the originality of their ideas and their sense of purpose and mission. The coup de grace of Minsky and Papert was an unfortunate event that braked the advancement of neural network theory for a number of years preceding publication of the path-breaking paper by Hopfield. It is this paper and the rediscovery of Paul Werbos' backpropagation algorithm by Rumelhart et al. that led to the ballistic ascent of neural-network-related research that we observe today.

The power of neural network theory derives in large measure from the fact that we possess the machinery for performing large volumes of computation at high speed, with high reliability and low cost. Without this machinery, neural network theory would be of academic interest. The stress on computational aspects of neural network theory is one of the many great strengths of "static and dynamic neural networks" (SDNNs). A particularly important contribution of SDNN is its coverage of the theory of dynamic neural networks and its applications.

Traditionally, science has been aimed at a better understanding of the world we live in, centering on mathematics and the natural sciences. But as we move further into the age of machine intelligence and automated reasoning, a major aim of science is becoming that of automation of tasks performed by humans, including speech understanding, decisionmaking, and pattern recognition and control.

To solve some of the complex problems that arise in these realms, we have to marshal all the resources that are at our disposal. It is this need that motivated the genesis of soft computing — a coalition of methodologies that are both complementary and synergistic — and that collectively provide a foundation for computational intelligence. Neural network theory is one of the principal members of the soft computing coalition — a coalition that includes, in addition, fuzzy logic, evolutionary computing, probabilistic computing, chaotic computing, and parts of machine learning theory. Within this coalition, the principal contribution of neural network theory is the machinery for learning, adaptation, and modeling of both static and dynamical systems.

One of the important contributions of SDNN is the chapter on fuzzy sets and fuzzy neural systems (Chapter 15), in which the authors present a compact exposition of fuzzy set theory and an insightful discussion of neurofuzzy systems and their applications. An important point that is stressed is that backpropagation is a gradient-based technique that applies to both neural and fuzzy systems. The same applies to the widely used methods employing radial basis functions.

Another important issue that is addressed is that of universal approximation. It is well known that both neural networks and fuzzy rule-based systems can serve as universal approximators. However, what is not widely recognized is that a nonlinear system, S, can be arbitrarily closely approximated by a neural network, N, or a fuzzy system, F, only if S is known, rather than merely given as a black box. The fact that S must be known rules out the possibility of asserting that N or F approximates to S to within a specified error, based on a finite number of exemplars drawn from the input and output functions.

An important aspect of the complementarity of neural network and fuzzy set theories relates to the fact that, in most applications, the point of departure in the construction of a fuzzy system for performing a specified task is the knowledge of how a human performs that task. This is not a necessity in the case of a neural network. On the other hand, it is difficult to construct a neural network with a capability to reason through the use of rules of inference, since such rules are a part of the machinery of fuzzy logic but not of neural network theory.

SDNN contains much that is hard to find in the existing literature. The quality of exposition is high and the coverage is thorough and up-to-date. The authors and the publisher, John Wiley and Sons, have produced a treatise that addresses, with high authority and high level of expertise, a wide variety of issues, problems, and techniques that relate in a basic way to the conception, design, and utilization of intelligent systems. They deserve our applause.

University of California, Berkeley *Lotfi A. Zadeh*

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Preface

With the evolution of our complex technological society and the introduction of new notions and innovative theoretical tools in the field of intelligent systems, the field of neural networks is undergoing an enormous evolution. These evolving and innovative theoretical tools are centered around the theory of *soft computing*, a theory that embodies the theory from the fields of *neural networks, fuzzy logic, evolutionary computing, probabilistic computing*, and *genetic algorithms*. These tools of soft computing are providing some intelligence and robustness in the complex and uncertain systems similar to those seen in natural biological species.

Intelligence — the ability to learn, understand, and adapt — is the creation of nature, and it plays a key role in human actions and in the actions of many other biological species. Humans possess some robust attributes of learning and adaptation, and that's what makes them so intelligent. We humans react through the process of learning and adaptation on the information received through a widely distributed network of sensors and control mechanisms in our bodies. The *faculty of cognition* — which is found in our carbon-based computer, the brain — acquires information about the environment through various natural sensory mechanisms such as vision, hearing, touch, taste, and smell. Then the process of cognition, through its intricate neural networks — *the cognitive computing* — integrates this information and provides appropriate actions. The cognitive process then advances further toward some attributes such as learning, recollection, reasoning, and control.

The process of cognition takes place through a perplexing biological process — *the neural computing* — and this is the process of computation that makes a human an intelligent animal. (More or less all animals possess intelligence at various levels, but *humans fall into the category of the most intelligent species.*)

Human actions in this advancing technological world have been inspired by many intriguing phenomena occurring in the nature. We have been inspired to fly by birds, and then we have created flying machines that can fly almost in synchrony with the sun.

We are learning from the carbon-based cognitive computer — the brain — and now trying to induce the process of cognition and intelligence into robotic machines. One of our aims is to construct an autonomous robotic vehicle that can think and operate in uncertain and unstructured driving conditions. Robots in manufacturing, mining, agriculture, space and ocean exploration, and health sciences are just a few examples of challenging applications where humanistic attributes such as *cognition* and *intelligence* can play an important role. Also, in the fields of decisionmaking, such as health sciences, management, economics, politics, law, and administration, some of the mathematical tools evolving around the notion of neural networks, fuzzy logic, and, in general, soft computing may contribute to the strength of the decisionmaking field. We envision robots evolving into electromechanical systems — perhaps having some attributes of human cognition.

The human cognitive faculty — the carbon-based computer — has a vast network of processing cells called *neural networks*, and this science of neural networks has inspired many researchers in biological as well as nonbiological fields. This inspiration has generated keen interest among engineers, computer scientists, and mathematicians for developing some basic mathematical models of neurons, and to use the collective actions of these neural models to find the solutions to many practical problems. The concepts evolved in this realm have generated a new field of *neural networks.*

The idea for this textbook on neural networks was conceived during the classroom teachings and research discussions in the laboratory as well as at international scientific meetings. We are pleased to see that our several years of work is finally appearing in the form of this book. This book, of course, has gone through several phases of writings and rewritings over the last several years.

The contents of this book, entitled *Static and Dynamic Neural Networks: From Fundamentals to Advanced Theory*, follows a logical style providing the readers the basic concepts and then leading them to some advanced theory in the field of neural networks.

The mathematical models of a basic neuron, the elementary components used in the design of a neural network, are a fascinating blend of heuristic concepts and mathematical rigor. It has become a subject of large interdisciplinary areas of teaching and research, and these mathematical concepts have been successfully applied in finding some robust solutions for problems evolving in the many fields of science and technology. Our own studies have been in the fields of *neurocontrol systems, neurovision systems, robotic systems, neural chaotic systems, pattern recognition*, and *signal and image processing*.

In fact, since the early 1980s the field of neural networks has undergone the phases of exponential growth, generating many new theoretical concepts. At the same time, these theoretical tools have been applied successfully to the solution of many applied problems.

Over the years, through their teaching and research in this exponentially evolving field of neural networks, the authors have collected a large volume of ideas. Some of their works have appeared in the form of research publications, and this present volume represents only a small subset of this large set of ideas and studies.

The material in this volume is arranged in a pedagogical style, which, we do hope, will serve both the students and researchers in this evolving field of neural networks.

In designing the present book we strove to present a pedagogically sound volume that would be useful as a main text for graduate students, as well as provide some new directions to academic and industrial researchers. We cover some important topics in neural networks from very basic to advanced material with appropriate examples, problems, and reference material.

In order to keep the book to a manageable size, we have been selective in our coverage. Our first priority was to cover the central concepts of each topic in enough detail to make the material clear and coherent. Each chapter has been written so that it is relatively self-contained. The topics selected for this book were based on our experience in teaching and research.

This book contains 15 chapters, which are classified into the following four parts:

Part I: Foundations of Neural Networks
(Chapters 1–3)
Part II: Static Neural Networks
(Chapters 4–7)

Part III: Dynamic Neural Networks
(Chapters 8–12)
Part IV: Some Advanced Topics in Neural Networks
(Chapters 13–15)

Part I provides the basic material, but from Parts II, III, and IV, instructors may choose material to suit their class needs. Part IV deals with some advanced topics on neural networks involving *fuzzy sets* and *fuzzy neural networks* as well, which have become very important topics in terms of both the theory and applications.

Also, we append this book with two appendixes:

Appendix A: Current Bibliographic Sources on Neural Networks
Appendix B: Classified List of Bibliography on Neural Networks (`ftp://ftp.wiley.com/public/sci_tech_med/neural_networks/`)

Appendix A provides various sources from which a student or researcher can find the current work in the field. Appendix B gives an extensive list of references (over 1500) classified into various categories on the ftp site:
`ftp://ftp.wiley.com/public/sci_tech_med/neural_networks/`
that will provide the readers with the information on reference material from its inception (early 1940s) to recent works.

This book is written for graduate students and academic and industrial researchers working in this developing field of neural networks and intelligent systems. It provides some comprehensive views of the field, as well as its accomplishments and future potentials and perspectives.

We do hope that this book will provide new challenges to its readers, that it will generate curiosity for learning more in the field, and that it will arouse a desire to seek new theoretical tools and applications. We will consider our efforts successful if the study of neural networks through this book raises the level of curiosity and thirst of its readers.

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GlobespanVirata, Inc. — *Liang Jin*
Tohoku University — *Noriyasu Homma*

Acknowledgments

The authors would like to express their appreciation and gratitude to many research colleagues and students from this international community who have inspired our thinking and, thereby, our research in these emerging field of fuzzy logic and neural networks. Indeed, we are pleased to see that the fruits of our teaching and research are finally appearing in the form of this textbook.

We wish to acknowledge the very constructive and positive feedback that we have received from the reviewers on the raw manuscript for this book. Their comments were very helpful in improving the contents of the book. Several of our students provided some very constructive feedback on the contents and organization of the book. We are grateful to Sanjeeva Kumar Redlapalli and Mubashshar Ahmed for helping us in the reorganization of the bibliography and in some proofreading of the text. We also acknowledge the great assistance of our graduate and undergraduate students at Tohoku University — Masao Sakai, Taiji Sugiyama, Misao Yano, and Yosuke Koyanaka — for helping us in making the diagrams and typing some of the manuscript.

Also the authors would like to thank John Wiley & Sons Inc. and its staff for providing valuable professional support during the various phases of the preparation of this book. Specifically we would like to acknowledge the following persons for their professional support: Philip Meyler (Former Editor), George Telecki (Associate Publisher), Val Moliere (Editor for the Wiley Interscience Division), Andrew Prince (Senior Managing Editor), Rosalyn

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Finally, we are very grateful to the University of Saskatchewan and our research colleagues and students in the College of Engineering for creating a warm teaching and intellectual research atmosphere for the nourishment of this book and many similar research projects and research publications over the years. Our gratitude is also extended to the staff of the Engineering Computer Centre and the Peter N. Nikiforuk Teaching and Learning Centre, in particular to Ian MacPhedren, Bruce Coates, Randy Hickson, and Mark Tomtene, for their continuous assistance that we received during the preparation of this manuscript.

We also acknowledge the very constructive help of our research assistant, Elizabeth Nikiforuk, who took on the challenging task of organizing and assembling the manuscript during the many phases of its preparation over the last several years.

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December, 2002

Part I

FOUNDATIONS OF NEURAL NETWORKS