# Fundamentals of Neural Network Modeling: Neuropsychology & Cognitive Neuroscience

# Fundamentals of Neural Network Modeling

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edited by Randolph W. Parks, Daniel S. Levine, and
Debra L. Long

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# Fundamentals of Neural Network Modeling

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# Series Foreword

Computational neuroscience is an approach to understanding the information content of neural signals by modeling the nervous system at many different structural scales, including the biophysical, the circuit, and the systems levels. Computer simulations of neurons and neural networks are complementary to traditional techniques in neuroscience. This book series welcomes contributions that link theoretical studies with experimental approaches to understanding information processing in the nervous system. Areas and topics of particular interest include biophysical mechanisms for computation in neurons, computer simulations of neural circuits, models of learning, representation of sensory information in neural networks, systems models of sensory-motor integration, and computational analysis of problems in biological sensing, motor control, and perception.

Terrence J. Sejnowski
Tomaso A. Poggio

# Preface

Neural networks began to be the object of serious research in the 1940s. They did not become widely known or popular until the 1980s when several academic centers published articles and distributed software that enabled individuals with modest mathematical and computing skills to learn computational network principles and apply them to broad ranges of projects inside university settings as well as in extramural domains. At first, neural networks were predominantly applied to industrial problems in areas such as pattern recognition and signal processing. However, many active neural network researchers were guided by insights from neuroscience and psychology, and believed that neural networks could become an important computational technique for furthering our understanding of brain and cognitive processes. This belief was borne out by significant progress in the field during the 1990s when substantial improvements in computer architecture, software design, and computing speed occurred. In particular, interest in applying neural networks to understanding neuropsychology and mental function and dysfunction has increased dramatically. Other colleagues such as neurologists, psychiatrists, and cross-disciplinary neuroscientists also have facilitated interest in this new field. The feasibility of making connections between models and clinical data has also increased, calling for a textbook that brings together much of this growing body of work in a single volume. This book is the first of its kind that is specifically intended for neuropsychologists and related disciplines.

Our book has models of many widely used neuropsychological tests and tasks, including the Wisconsin Card Sorting, Stroop, verbal fluency, Tower of Hanoi, Line Cancellation, and many other tests. It covers a wide range of syndromes, including Alzheimer's disease, Parkinson's disease, schizophrenia, epilepsy, alcoholism, stroke, attention deficit/hyperactivity disorder, and frontal lobe disorders. The modeling techniques utilized are not dominated by one "school" of modeling; rather, they include widely used modeling paradigms, such as backpropagation and adaptive resonance, and models designed for a systems approach to interacting brain regions implicated in cognitive tasks. In addition, some chapters have been included to facilitate a better understanding of the neurobiological and neuroanatomical basis of cognitive network models.

Prerequisites of a technical nature are minimized in this book. The mathematics involved in the network models are deemphasized, and in most cases the theoretical basis for the model's structure can be discerned from the diagrams combined with the text. Hence, the aim is to present neural network techniques as theoretical tools that can be readily learned and applied by neuropsychologists and other neuroscientists (including neurologists, psychiatrists, clinical psychologists, mathematicians, and computer scientists) with particular interest in clinical patient applications. We hope that this will contribute to the accessibility of neural networks and to an intensification of the ongoing dialogue between the clinical and theoretical communities.

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# Contents

# I Introduction to Neural Networks

# 1 An Introduction to Neural Network Modeling: Merits, Limitations, and Controversies

Debra L. Long, Randolph W. Parks, and
Daniel S. Levine

Many researchers in cognitive psychology and neuropsychology have described human mental activity in terms of abstract information-processing models. Still other researchers have focused on regional brain areas associated with hypothesized neuropsychological test performance without an appreciation of multiple brain regions' contributions to cognitive test performance. However, these traditions have been supplemented in recent years by efforts to develop models of cognitive processes that are better founded in our understanding of neural circuitry. Researchers who have adopted a neural network approach attempt to model cognition as patterns of activity across simple computing elements or units (Feldman & Ballard, 1982; Grossberg, 1982, 1988; McClelland, Rumelhart, & the PDP Research Group, 1986; Rumelhart & McClelland, 1986). Such models have been used to investigate theoretical claims about the nature of various cognitive processes (e.g., pattern recognition, attention, semantic memory, natural language processing) and to solve a wide range of applied problems (e.g., machine vision, medical diagnosis, speech recognition and production).

In this chapter, we use the term *neural network* broadly to refer to a large class of models that share certain architectural and processing features: (1) these models contain many simple processing elements or units that operate in parallel; (2) the units in these models communicate activation along connections (weights) of varying strength; and (3) the models learn by adjusting their weights as they gain experience in some environment. Models of this type have also been called *connectionist models* and *parallel distributed processing models*.

Neural network models were introduced to mainstream psychologists and computer scientists in several influential publications, including Feldman and Ballard (1982), Hopfield (1982), and Rumelhart and McClelland (1986). Since that time, these models have been the topic of substantial theoretical and computational interest and the source of considerable controversy.

The main ideas involved in neural network modeling have a substantial history (see Anderson & Rosenfeld, 1988; Levine, 1983, 1991; and Parks et al., 1991, for partial accounts). An influential article in the field was published by McCulloch and Pitts in 1943. They demonstrated that any logical function could be duplicated by a suitable network of all-or-none neurons with thresholds. Biological underpinnings of neural network theory were added by two researchers in particular: Hebb (1949), who formally proposed that learning depends on synaptic weight changes in response to paired pre- and postsynaptic stimuli; and Rashevsky (1960), who proposed methods for averaging the all-or-none behavior of single neurons into continuous dynamics of large neural ensembles. Rosenblatt (1962), Werbos (1974), and others combined McCulloch and Pitts's insights with Hebb's in developing the ancestors of current error-correcting learning networks, such as Rumelhart and McClelland's (1986) backpropagation network. Grossberg (e.g., 1969) pioneered the development of continuous dynamical system networks that embodied psychological principles such as associative learning and lateral inhibition. Such principles were also explored by several other researchers who are still leaders in the neural network field, such as Amari (1971), Anderson (1968, 1970), and Kohonen (1977).

Our purpose in this book is to make the neural network approach accessible to practicing neuropsychologists, clinical psychologists, neurologists, psychiatrists, and research neuroscientists (including mathematicians and computer scientists) who may have little substantive knowledge of the topic. The chapters gathered here describe recent advances in the application of neural network modeling to a wide range of topics. Part I provides an overview of neural network modeling. The chapters in part I describe the basic architecture of neural networks and discuss some of the assumptions that underlie this approach. In addition, the chapters describe the application of these models to theoretical topics such as attention and hippocampal contributions to memory. The chapters in part II describe neural network models of behavioral states, such as alcohol dependence, learned helplessness, depression, and waking and sleeping. Part III is devoted to neural network models of neuropsychological tests such as the Stroop, Tower of Hanoi, and Line Cancellation tests. In addition, the chapters in this section describe the application of these models to syndrome-specific topics such as schizophrenia, acalculia, neglect, attention deficit/hyperactivity disorder, and lexical retrieval. The final section, part IV, describes the application of neural network models to dementia. These chapters describe models of acetycholine and memory, frontal lobe syndrome, Parkinson's disease, and Alzheimer's disease. The Wisconsin Card Sorting and verbal fluency tests are modeled within the dementia framework.

Our goal in this first chapter is to provide a comprehensive introduction to principles of neural network modeling. In the first section, we describe the basic architecture of neural networks and contrast these models with the traditional symbolic models used in artificial intelligence (AI). In addition, we provide details about two of the most popular classes of network models, *backpropagation networks* and networks based on *adaptive resonance theory* (ART). In the second section, we discuss some of the controversies surrounding the neural network approach. Should cognition be modeled using