OPTIMALITY IN BIOLOGICAL AND ARTIFICIAL NETWORKS?

EDITED BY
DANIEL S. LEVINE
WESLEY R. ELSBERRY

OPTIMALITY IN BIOLOGICAL AND ARTIFICIAL NETWORKS?

Edited by

DANIEL S. LEVINE
University of Texas, Arlington

WESLEY R. ELSBERRY
Texas A&M University

LEA LAWRENCE ERLBAUM ASSOCIATES, PUBLISHERS
1997 Mahwah, New Jersey

The final camera copy for this work was prepared by the editors, and therefore the print quality is not up to the usual specifications for LEA publications. However, this arrangement helps to make publication of this kind of scholarship possible.

Lawrence Erlbaum Associates, Inc., Publishers
10 Industrial Avenue
Mahwah, New Jersey 07430

Cover design by Debra Karrel

Library of Congress Cataloging-in-Publication Data

Levine, Daniel S.
Optimality in biological and artificial networks? / Daniel S.
Levine, Wesley R. Elsberry.
p. cm.
Includes bibliographical references and index.
ISBN 0-8058-1561-9(alk. paper)
1. Neural networks (computer science) 2. Artificial intelligence.
I. Elsberry, Wesley R. II. Title
QA76.87.L477 1996
006.3--DC20 96-42260
CIP

Books published by Lawrence Erlbaum Associates are printed on acid-free paper, and their bindings are chosen for strength and durability.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

OPTIMALITY IN BIOLOGICAL AND ARTIFICIAL NETWORKS?

THE INTERNATIONAL NEURAL NETWORKS SOCIETY SERIES

Harold Szu, Editor

Alspector/Goodman/Brown • *Proceedings of the International Workshop on Applications of Neural Networks to Telecommunications* (1993)

Alspector/Goodman/Brown • *Proceedings of the International Workshop on Applications of Neural Networks to Telecommunications, Vol. 2* (1995)

Freeman • *Societies of Brains: A Study in the Neuroscience of Love and Hate* (1995)

King/Pribram • *Scale in Conscious Experience: Is the Brain too Important to be left to Specialists to Study?* (1995)

Lenaris/Grossberg/Kosko • *World Congress on Neural Networks: Proceedings of the 1993 INNS Annual Meeting*

Levine/Elsberry • *Optimality in Biological and Artificial Networks?* (1997)

Pribram • *Rethinking Neural Networks: Quantum Fields and Biological Data* (1993)

Pribram • Origins: *Brain and Self-Organization* (1994)

Pribram/King • *Learning as Self-Organization* (1996)

Sobajic • *Neural Network Computing for the Electric Power Industry* (1993)

List of Contributors

Hervé Abdi, University of Texas at Dallas, School of Human Development GR41, Box 830688, Richardson, TX 75083, or CCUB-CRIC Faculte des Sciences Mirandes, Universite de Bourgogne, 21004 Dijon Cédex, France (herve@utdallas.edu or herve@u-bourgogne.fr)

Samy Bengio, INRS —Télécommunications, 16, Place du Commerce, Verdun, Québec, Canada H3E 1H6 (bengio@inrs-telecom.uquebec.ca)

Yoshua Bengio, Université de Montréal, Dept IRO, C.P. 6128, Succ. Centre-Ville, Montréal, Québec, Canada, H3C 3J7 (bengioy@iro.umontreal.ca)

Basabi Bhaumik, Department of Electrical Engineering, Indian Institute of Technology (Delhi), Hauz Khas, New Delhi, 110016, India (bhaumik@ee.iitd.ernet.in)

Raymond T. Bradley, Institute for Whole Social Science, 35400 Telarana Way, Carmel, CA 93923

Sylvia Candelaria de Ram, 2080 Boise Drive, Las Cruces, NM 88003 (cogandcomm@delphi.com)

Gail A. Carpenter, Center for Adaptive Systems, Boston University, 677 Beacon Street, Boston, MA 02215 (gail@cns.bu.edu)

David C. Chance, HC-1 BOX 139, Eagle Rock, MO 65641 (dchance660@aol.com)

John Y. Cheung, School of Electrical Engineering, University of Oklahoma, Norman, OK 73019

Jocelyn Cloutier, AT&T Bell Laboratories, 101 Crawfords Corner Road, Holmdel, NJ 07733 (jocelyn@big.att.com)

Mark R. DeYong, Intelligent Reasoning Systems, Inc., 7801 North Lamar (Suite E216), Austin, TX 78752 (mark@irsinc.com)

Robert E. Dorsey, School of Business Administration, University of Mississippi, 218 Conner Hall, University, MS 38677

Wesley R. Elsberry, 6070 Sea Isle, Galveston, TX 77554 (welsberr@orca.tamu.edu)

Thomas Eskridge, Intelligent Reasoning Systems, Inc., 7801 North Larar (Suite E216), Austin, TX 78752 (tom@irsinc.com)

Jan Gecsei, Université de Montréal, Dept IRO, C.P. 6128, Succ. Centre-Ville, Montréal, Québec, Canada H3C 3J7 (gecsei@iro.umontreal.ca)

Richard Golden, University of Texas at Dallas, School of Human Development GR41, Box 830688, Richardson, TX 75083 (golden@utdallas.edu)

Bernie Jackson, Department of Computer Science, Stanford University, Jordan Hall, Stanford, CA 94305

Arun Jagota, Department of Computer Science, 225 Applied Science, Baskin Center, University of California at Santa Cruz,Santa Cruz, CA (jagota@icsi.berkeley.edu)

Jayadeva, Department of Electrical Engineering, Indian Institute of Technology (Delhi), Hauz Khas, New Delhi, 110016, India (jayadeva@ee.iitd.ernet.in)

John D. Johnson, School of Business Administration, University of Mississippi, 218 Conner Hall, University, MS 38677 (johnson@bus.olemiss.edu)

Asa W. Lawton, School of Computer Science, University of Oklahoma, Norman, OK 73019

Sam Leven, For a New Social Science, 4681 Leitner Drive West, Coral Springs, FL 33067 (samnets@aol.com)

Daniel S. Levine, Department of Psychology, University of Texas at Arlington, Arlington, TX 76019, or Department of Mathematics, University of Texas at Arlington, 411, S. Nedderman Drive, Arlington, TX 76019 (b344dsl@utarlg.uta.edu)

Sue Lykins, Departmentof Psychology, Oklahoma State University, Stillwater, OK 74078

Haluk Öğmen, Department of Electrical Engineering, University of Houston, Houston, TX 77204 (ogmen@uh.edu)

Alice J. O'Toole, University of Texas at Dallas, School of Human Development GR41, Box 830688, Richardson, TX 75083 (otoole@udallas.edu)

Ian Parberry, Department of Computer Sciences, University of North Texas, P.O. Box 13886, Denton, TX 76203 (ian@ponder.csci.unt.edu)

Karl H. Pribram, Director, Center for Brain Research and Informational Sciences, Radford University, Radford, VA 24142 (kpribram@ruacas.ac.runet.edu)

Ramkrishna V. Prakash, Department of Electrical Engineering, University of Houston, Houston, TX 77204 (prakash@uh.edu)

Paul Prueitt, Highland Technologies, Inc., 4303 Forbes Boulevard, Lanham, MD 20706 (paul@htech.com)

Gershom-Zvi Rosenstein, Department of Physiology, Hadassah Medical School, Hebrew University, 91010 Jerusalem, Israel (rosen@md2.huji.ac.il)

David G. Stork, Ricoh California Research Center, 2882 Sand Hill Road, Suite 115, Menlo Park, CA 94025 (stork@crc.ricoh.com)

Graham D. Tattersall, New House, Mill Road, Friston, Suffolk IP17 IPH, United Kingdom (gdt@sys.uea.ac.uk)

Dominique Valentin, University of Texas at Dallas, School of Human Development GR41, Box 830688, Richardson, TX 75083 (valentin@utdallas.edu)

Scott Walker, Department of Computer Science, Stanford University, Jordan Hall, Stanford, CA 94305

Paul J. Werbos, 8411 48th Avenue, College Park, MD 20740 (pwerbos@note.nsf.gov)

Preface

This book is the third of a series of books based on conferences sponsored by the Metroplex Institute for Neural Dynamics (M.I.N.D), an interdisciplinary organization of Dallas-Fort Worth area neural network professionals in both academia and industry. M.I.N.D. sponsors a conference every year or two on some topic within neural networks. The topics are chosen (a) to be of broad interest both to those interested in designing machines to perform intelligent functions and those interested in studying how these functions are actually performed by living organisms, and (b) to generate discussion of basic and controversial issues in the study of mind. The subjects are chosen for depth and fascination of the problems covered, rather than for the availability or airtight conclusions; hence, well-thought-out speculation is encouraged at these conferences. Thus far, the topics have been as follows:

May 1988 — Motivation, Emotion, and Goal Direction in Neural Networks
June 1989 — Neural Networks for Adaptive Sensory-Motor Control
October 1990 — Neural Networks for Knowledge Representation and Inference
February 1992 — Optimality in Biological and Artificial Networks?
May 1994 — Oscillations in Neural Systems
May 1995 — Neural Networks for Novel High-Order Rule Formation

A book based on the May 1988 conference was published by Lawrence Erlbaum Associates, Inc. (LEA), in 1992. A book based on the October 1990 conference was published by LEA in 1994. The current book is based on the February 1992 conference, and one based on the May 1994 conference is in its early stages.

The topic of optimality was chosen because it has provoked considerable discussion and controversy in many different academic fields (see, in particular, Schoemaker, 1991). There are several aspects to the issue of optimality. First is it true that actual behavior and cognitive function of living animals, including humans, can be considered optimal in some sense? Is there a measurable *utility function,* to use the economists' term, or at least a utility function deducible on theoretical grounds, that all actions ultimately serve to maximize? Or is most actual human or animal behavior better described by what the economist and cognitive scientist Herbert Simon (1979) called *satisficing* — in colloquial terms, "muddling through" or "making do" with solutions that may not be the best possible, but are in some measurable sense good enough? The answer to this question is still unknown, which is one reason for the question mark in this book's title.

Second, what *is* the utility function for biological organisms, if any, and can it be described mathematically? Even if all behavior does not fit the maximization paradigm, as Schoemaker (1991) has suggested, optimality might provide a *normative* criterion for which behaviors are desirable or should be encouraged. This kind of normative criterion can also guide the design of artificial neural networks to perform engineering tasks, whether in robotics, pattern recognition, business applications such as scheduling, or a variety of other situations. If not all biological behavior is in fact optimal, this also suggests that although designers of intelligent machines should understand the biological functions of the brain as well as possible, they should not adhere slavishly to "biological realism" in the architectures for their machines.

So the questions posed by the participants in this conference tended to fall into the categories of (a) *how* to optimize particular functions, in both biological and artificial networks and (b) *whether* particular functions are in fact performed optimally by particular biological or artificial networks. Rather than organize the chapters by what stance they took on optimality, it seemed more natural to organize them either by what level of questions they posed or by what intelligent functions they dealt with. This led to four major sections, including the following authors:

What Is the Role of Optimality?

Daniel Levine
Paul Werbos
Sam Leven
David Stork, Bernie Jackson, and Scott Walker
Wesley Elsberry
Mark DeYong and Thomas Eskridge

Quantitative Foundations of Neural Optimality

Paul Prueitt
Ian Parberry
Richard Golden
Graham Tattersall
Robert Dorsey and John Johnson
Arun Jagota

Optimality in Learning, Cognition, and Perception

David Chance, John Cheung, Sue Lykins, and Asa Lawton
Samy Bengio, Yoshua Bengio, Jocelyn Cloutier, and Jan Gescei
Gail Carpenter
Hervé Abdi, Dominique Valentin, and Alice O'Toole
Jayadeva and Basabi Bhaumik

Optimality in Decision, Communication, and Control

Haluk Öğmen and Ramkrishna Prakash
Gershom-Zvi Rosenstein
Sylvia Candelaria de Ram
Raymond Bradley and Karl Pribram

The chapters in the first section set some general frameworks for discussing optimality, or the lack of it, in biological artificial systems. The second section deals with some general mathematical and computational theories that help to clarify what the notion of optimality might entail in specific classes of networks. The chapters in the third section begin with optimizing rules for changing connection weights to facilitate associative learning, then move on to optimizing various processes in visual pattern perception. The chapters in the final section deal with optimality in the context of many different high-level issues, including exploring one's environment, understanding mental illness, linguistic communication, and finally, social organization.

The diversity of topics covered in this book is designed to stimulate interdisciplinary thinking and speculation about deep problems in intelligent system organization. This can have the unfortunate side effect of creating confusion for the reader by leading the reader to believe that many of the chapters are unrelated. At the suggestion of one of the book's anonymous reviewers, we have attempted to mitigate this possible confusion by writing prefaces at the start of each chapter, preceding the abstract. These prefaces are designed not only to frame the problem posed by the chapter's authors but also to show salient relationships between the chapter and others in this book.

In addition to the chapter authors, we acknowledge contributions made to this volume by several other individuals and organizations. The conference on which this book is based was made possible by generous financial support from two other organizations in addition to M.I.N.D. One was For a New Social Science (NSS), a nonprofit research foundation based in Coral Springs, Florida, that also cosponsored the M.I.N.D. 1995 conferences and supported the 1990 conference. The purpose of NSS, as stated by its founder, Dr. Sam Leven, is "turning the findings and techniques of science to the benefit of social science." It seeks to develop more predictive methodological bases for areas ranging from economics to management theory to social psychology — in some cases, to replace foundational assumptions dating from the time of David Hume and Adam Smith, based on a static and unrealistic model of human behavior, with new foundational assumptions that draw on modern knowledge of neuroscience, cognitive science, and neural network theory. The other organization that supported the conference as the International Neural Network Society (INNS), through its Texas Area Special Interest Group (SIG), and administered by the then Executive Director of INNS, Morgan Downey. INNS, founded in 1987, has become the flagship interdisciplinary organization for neural network researchers and practitioners, through several World Congresses on Neural Networks that draw around 500 attendees and the society's official Journal, Neural Networks (published by Elsevier). INNS is now involved with this book in another respect, having joined forces with Lawrence Erlbaum Associates, Inc., to promote an INNS Book Series of which this book is a part.

The speakers and poster presenters at the conference included one author for each chapter in this book except for Chapters 2 and 17, and several other distinguished neural network researchers: Stephen Grossberg of Boston University (whose talk is mentioned in the editors' preface to Gail Carpenter's chapter); Harold Szu of the Naval Surface Warfare Center (whose ideas are alluded to in Robert Dorsey and John Johnson's chapter); Steven Hampson of the University of California at Irvine; and Subhash Kak of Louisiana State University. These speakers made strong contributions to the dialogue. Some could not contribute chapters to the book because of other time commitments, and others were not asked to contribute because the anonymous reviewers expressed the need to focus the dialogue more sharply, but their influence is felt in the points raised by the chapter authors.

The other members of the Metroplex Institute for Neural Dynamics lent us considerable organizational support, especially Alice O'Toole and Raju Bapi, who were with us on the M.I.N.D. executive committee at the time of the conference. The University of Texas at Dallas provided the excellent Conference Center with state-of-the-art facilities at which the meeting took place.

We owe a debt of thanks to the staff of Lawrence Erlbaum Associates, Inc., particularly to Judi Amsel and Ray O'Connell, our editors at different stages; our unknown copyeditor; and Arthur Lizza and Sondra Guideman, our production editors. Ray, in particular, promoted this book as a natural sequel to the book on knowledge representation and inference.

Finally, we thank our wives, Lorraine Levine and Diane Blackwood, for their patience and support. Their intuitive understanding of and proximity to our editorial efforts made them in effect cocreators with us.

Daniel S. Levine
Wesley R. Elsberry

References

Schoemaker, P. J. H. (1991).The quest for optimality: A positive heuristic of science? *Behavioral and Brain Sciences,* **14,** 205-245.

Simon, H. A. (1979). *Models of Thought.* New Haven, CT: Yale University Press.

Contents

I

WHAT IS THE ROLE OF OPTIMALITY?