FOUNDATIONS OF NEURAL NETWORKS, FUZZY SYSTEMS, AND KNOWLEDGE ENGINEERING

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FOUNDATIONS OF NEURAL NETWORKS, FUZZY SYSTEMS, AND KNOWLEDGE ENGINEERING

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To my mother and the memory of my father,
and to my family, Diana, Kapka, and Assia

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Foreword

We are surprisingly flexible in processing information in the real world. The human brain, consisting of 10^{11} neurons, realizes intelligent information processing based on exact and commonsense reasoning. Scientists have been trying to implement human intelligence in computers in various ways. Artificial intelligence (AI) pursues exact logical reasoning based on symbol manipulation. Fuzzy engineering uses analog values to realize fuzzy but robust and efficient reasoning. They are macroscopic ways to realize human intelligence at the level of symbols and rules. Neural networks are a microscopic approach to the intelligence of the brain in which information is represented by excitation patterns of neurons.

All of these approaches are partially successful in implementing human intelligence, but are still far from the real one. AI uses mathematically rigorous logical reasoning but is not flexible and is difficult to implement. Fuzzy systems provide convenient and flexible methods of reasoning at the sacrifice of depth and exactness. Neural networks use learning and self-organizing ability but are difficult for handling symbolic reasoning. The point is how to design computerized reasoning, taking account of these methods.

This book solves this problem by combining the three techniques to minimize their weaknesses and enhance their strong points. The book begins with an excellent introduction to AI, fuzzy-, and neuroengineering. The author succeeds in explaining the fundamental ideas and practical methods of these techniques by using many familiar examples. The reason for his success is that the book takes a problem-driven approach by presenting problems to be solved and then showing ideas of how to solve them, rather than by following the traditional theorem-proof style. The book provides an understandable approach to knowledge-based systems for problem solving by combining different methods of AI, fuzzy systems, and neural networks.

Shun-ichi Amari
Tokyo University
June 1995

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Preface

The symbolic AI systems have been associated in the last decades with two main issues—the representation issue and the processing (reasoning) issue. They have proved effective in handling problems characterized by exact and complete representation. Their reasoning methods are sequential by nature. Typical AI techniques are propositional logic, predicate logic, and production systems.

However, the symbolic AI systems have very little power in dealing with inexact, uncertain, corrupted, imprecise, or ambiguous information. Neural networks and fuzzy systems are different approaches to introducing humanlike reasoning to knowledge-based intelligent systems. They represent different paradigms of information processing, but they have similarities that make their common teaching, reading, and practical use quite natural and logical. Both paradigms have been useful for representing inexact, incomplete, corrupted data, and for approximate reasoning over uncertain knowledge. Fuzzy systems, which are based on Zadeh's fuzzy logic theory, are effective in representing explicit but amgibuous commonsense knowledge, whereas neural networks provide excellent facilities for approximating data, learning knowledge from data, approximate reasoning, and parallel processing. Evidence from research on the brain shows that the way we think is formed by sequential and parallel processes. Knowledge engineering benefits greatly from combining symbolic, neural computation, and fuzzy computation.

Many recent applications of neural networks and fuzzy systems show an increased interest in using either one or both of them in one system. This book represents an engineering approach to both neural networks and fuzzy systems. The main goal of the book is to explain the principles of neural networks and fuzzy systems and to demonstrate how they can be applied to building knowledge-based systems for problem solving. To achieve this goal the three main subjects of the book—knowledge-based systems, fuzzy systems, and neural networks—are described at three levels: a conceptual level; an intermediate, logical level; and a low, generic level in chapters 2, 3, and 4, respectively. This approach makes possible a comparative analysis between the rule-based, the connectionist, and the fuzzy methods for knowledge-engineering.

The same or similar problems are solved by using AI rule-based methods, fuzzy methods, connectionist methods, hybrid AI-connectionist, or hybrid fuzzy-connectionist methods and systems. Production systems are chosen as the most widely used paradigm for knowledge-engineering.

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Symbolic AI production systems, fuzzy production systems, connectionist production systems, and hybrid connectionist production systems are discussed, developed, and applied throughout the book. Different methods of using neural networks for knowledge representation and processing are presented and illustrated with real and benchmark problems (see chapter 5). One approach to using neural networks for knowledge engineering is to develop connectionist expert systems which contain their knowledge in trained-in-advance neural networks. The learning ability of neural networks is used here for accumulating knowledge from data even if the knowledge is not explicitly representable. Some learning methods allow the knowledge engineer to extract explicit, exact, or fuzzy rules from a trained neural network. These methods are also discussed in chapter 5. There are methods to incorporate both knowledge acquired from data and explicit heuristic knowledge in a neural network. This approach to expert systems design provides an excellent opportunity to use collected data (existing databases) and prior knowledge (rules) and to integrate them in the same knowledge base, approximating reality.

Another approach to knowledge engineering is using hybrid connectionist systems. They incorporate both connectionist and traditional AI methods for knowledge representation and processing. They are usually hierarchical. At a lower level they use neural networks for rapid recognition, classification, approximation, and learning. The higher level, where the final solution of the problem has to be communicated, usually contains explicit knowledge (see chapter 6). The attempt to use neural networks for structural representation of existing explicit knowledge has led to different connectionist architectures. One of them is connectionist production systems. The fusion between neural networks, fuzzy systems, and symbolic AI methods is called "comprehensive AI." Building comprehensive AI systems is illustrated in chapter 6, using two examples—speech recognition and stock market prediction.

Neural networks and fuzzy systems may manifest a chaotic behavior on the one hand. On the other, they can be used to predict and control chaos. The basics of chaos theory are presented in chapter 7. When would neural networks or fuzzy systems behave chaotically? What is a chaotic neural network? These and other topics are discussed in chapter 7. Chapter 7 also comments briefly on new developments in neural dynamics and fuzzy systems.

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This book represents an engineering problem-driven approach to neural networks, fuzzy systems, and expert systems. The main question answered in the book is: If we were given a difficult AI problem, how could we apply neural networks, or fuzzy systems, or a hybrid system to solve the problem? Pattern recognition, speech and image processing, classification, planning, optimization, prediction, control, decision making, and game simulations are among the typical generic AI problems discussed in the book, illustrated with concrete, specific problems.

The biological and psychological plausibility of the connectionist and fuzzy models have not been seriously tackled in this book, though issues like biological neurons, brain structure, humanlike problem solving, and the psychological roots of heuristic problem-solving are given attention.

This book is intended to be used as a textbook for upper undergraduate and postgraduate students from science and engineering, business, art, and medicine, but chapters 1 and 2 and some sections from the other chapters can be used for lower-level undergraduate courses and even for introducing high school students to AI paradigms and knowledge-engineering. The book encompasses my experience in teaching courses in Knowledge Engineering, Neural Networks and Fuzzy Systems, and Intelligent Information Systems. Chapters 5 and 6 include some original work which gives the book a little bit of the flavor of a monograph. But that is what I teach at the postgraduate level.

The material presented in this book is "software independent." Some of the software required for doing the problems, questions, and projects sections, like speech processors, neural network simulators, and fuzzy system simulators, are standard simulators which can be obtained in the public domain or on the software market, for example, the software package MATLAB. A small education software environment and data sets for experimenting with are explained in the appendixes.

I thank my students and associates for the accurately completed assignments and experiments. Some of the results are included in the book as illustrations. I should mention at least the following names: Jay Garden, Max Bailey, Stephen Sinclair, Catherine Watson, Rupert Henderson, Paul Jones, Chris Maffey, Richard Kilgour, Tim Albertson, Grant Holdom, Andrew Gray, Michael Watts, and Jonas Ljungdahl from the University of Otago, Dunedin, New Zealand; Stephan Shishkov, Evgeni Peev, Rumen Trifonov, Daniel Nikovski, Nikolai Nikolaev, Sylvia Petrova, Petar

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Kalinkov, and Christo Neshev from the Technical University in Sofia, Bulgaria; and L. Chen and C. Tan, masters students from the University of Essex, England, during the year 1991.

In spite of the numerous experiments applying neural networks and fuzzy systems to knowledge-engineering which I have conducted with the help of students and colleagues over the last 8 years, I would probably not have written this book without the inspiration I received from reading the remarkable monograph of Bart Kosko, *Neural Networks and Fuzzy Systems* (Englewood Cliffs, NJ, Prentice Hall, 1992); nor without the discussions I have with Shun-ichi Amari, Lotfi Zadeh, Teuvo Kohonen, John Taylor, Takeshi Yamakawa, Ron Sun, Anca Ralescu, Kunihiko Fukushima, Jaap van den Herik, Duc Pham, Toshiro Terano, Eli Sanches, Guido Deboeck, Alex Waibel, Nelson Morgan, Y. Takagi, Takeshi Furuhashi, Toshio Fukuda, Rao Vemuri, Janusz Kacprzyk, Igor Aleksander, Philip Treleaven, Masumi Ishikawa, David Aha, Adi Bulsara, Laslo Koczy, Kaoru Hirota, Jim Bezdek, John Andreae, Jim Austin, Lakmi Jain, Tom Gedeon, and many other colleagues and pioneers in the fields of neural networks, fuzzy systems, symbolic AI systems, and nonlinear dynamics. Before I finished the last revision of the manuscript a remarkable book was published by The MIT Press: *The Handbook of Brain Theory and Neural Networks*, edited by Michael Arbib. The handbook can be used for finding more detail on several topics presented and discussed in this book. It took me three years to prepare this book. Despite the many ups and downs encountered during that period I kept believing that it would be a useful book for my students. I thank my colleagues from the Department of Information Science at the University of Otago for their support in establishing the courses for which I prepared this book, especially my colleagues and friends Martin Anderson, Philip Sallis, and Martin Purvis. Martin Anderson carefully read the final version of the book and made many valuable comments and suggestions for improvement. I would like to thank Tico Cohen for his cooperation in the experiments on effluent water flow prediction and sewage process control. I was also encouraged by the help Gaynor Corkery gave me as she proofread the book in its preliminary version in 1994.

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