Fuzzy and Neural Approaches in Engineering

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Lotfi A. Zadeh

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FUZZY AND NEURAL APPROACHES IN ENGINEERING

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To
Demetra
and
Paula

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FOREWORD

To say that *Fuzzy and Neural Approaches in Engineering* is an important work is an understatement. With skill, authority, and insight, Professors Tsoukalas and Uhrig share with us their expertise in a new field that holds much promise and offers a fertile ground for the development of unorthodox techniques and novel applications.

Basically, the book reflects the proliferation and wide-ranging impact of systems that achieve a high level of performance through the employment of the methodologies of fuzzy logic and neurocomputing, singly or in combination. Systems in which fuzzy logic and neurocomputing are used in combination have come to be known as neurofuzzy systems. Takagi and Hayashi in Japan were among the first to describe such systems in 1988. Today, neurofuzzy systems are growing rapidly in number, visibility, and importance.

Viewed in a broader perspective, neurofuzzy systems constitute a subclass of systems based on "soft computing." The essence of soft computing (SC) is that unlike the traditional, hard computing, it is aimed at an accommodation with the pervasive imprecision of the real world. Thus, the guiding principle of soft computing is: Exploit the tolerance for imprecision, uncertainty, and partial truth to achieve tractability, robustness, low-solution cost, and better rapport with reality. In the final analysis, the role model for soft computing is the human mind.

Soft computing is not a single methodology. Rather, it is a consortium. The principal members of the consortium at this juncture are fuzzy logic (FL), neurocomputing (NC), genetic computing (GC), and probabilistic reasoning (PR), with the latter subsuming evidential reasoning, belief networks, chaotic systems, management of uncertainty, and parts of machine-learning theory. Within SC, the main contribution of FL is a methodology for dealing with imprecision, approximate reasoning, rule-based systems, and computing with words; that of NC is system identification, learning, and adaptation; that of GC is systematized random research and optimization; and that of PR is decision analysis and management of uncertainty.

In the main, FL, NC, GC, and PR are synergistic and complementary rather than competitive. For this reason, it is frequently advantageous to use FL, NC, GC, and PR in combination rather than exclusively, leading to so-called "hybrid systems." Today, the most visible systems of this type are neurofuzzy systems. We are also beginning to see fuzzy-genetic, neuro-genetic, and neurofuzzy-genetic systems. Such systems are likely to become ubiquitous in the not-so-distant future. Concomitantly, the realization that FL, NC, GC, and PR are complementary rather than competitive may put an end to inconclusive debates regarding the superiority of a particular member of the SC consortium over others.

Although *Fuzzy and Neural Approaches in Engineering* is concerned mainly with neurofuzzy systems, the authors address in the last chapters some of the basic aspects of genetic computing and present a succinct and up-to-date account of neurogenetic and fuzzygenetic systems. In this way, their treatise gains in generality and highlights the central role of soft computing in the conception, design, and deployment of intelligent systems.

The organization of the book reflects the basic structure of soft computing. The first six chapters are given over to the exposition of fuzzy logic and its applications. The next six chapters do the same for neurocomputing. The following five chapters present a highly informative and insightful exposition of ways in which fuzzy logic and neurocomputing can be used in combination. The value of these chapters is enhanced by the inclusion of many examples of real-world applications.

What is important to recognize—and what the authors stress—is that the synergism of fuzzy logic and neurocomputing is a two-way street. They do this by devoting a chapter to the discussion of fuzzy methods in neural networks, followed by a chapter on neural methods in fuzzy systems.

An observation which I would like to add is that in many, perhaps most, of the applications of fuzzy logic, the point of departure is a human solution. Thus, fuzzy logic—and, more specifically, the calculus of fuzzy *if/then* rules —is used as a quasi-programming language to express the human solution as a fuzzy rule-set or, more generally, as a fuzzy algorithm. In this sense, fuzzy logic solutions are for the most part descriptive rather than prescriptive.

A case in point is the problem of parking a car. In the fuzzy logic solution of this problem, the starting point is the human knowledge of how to park a car. The next step is to express this knowledge in the language of fuzzy *if/then* rules.

The descriptive approach may fail even though a human solution may exist. For example, one may be able to recognize a person by the way in which that person walks and yet be unable to articulate the fuzzy *if/then* rules that underlie the recognition. The problem of articulating—in the language of fuzzy *if/then* rules—what is subconscious or intuitive is a challenge that has not as yet been fully met.

Although there are many situations in which the problem of articulation remains to be solved, there are many more situations in which articulation is possible, either directly or through the use of rule induction techniques. These issues lie at the center of applications of fuzzy logic, including those applications in which fuzzy methods are used in neural networks.

Fuzzy and Neural Approaches in Engineering makes a major contribution to a better understanding of how fuzzy logic and neurocomputing can be applied, both singly and in combination, to the conception and design of a wide variety of systems. Professors Tsoukalas and Uhrig deserve our thanks and congratulations for producing a text that is informative, insightful, well-written, and forward-looking in both spirit and content.

LOTFI A. ZADEH

PREFACE

Soft computing is the name that is being put forth as an alternative to artificial intelligence for the plethora of advanced information processing technologies that have emerged in the past decade. This new field is characterized by a certain tolerance for imprecision and ambiguity and it includes expert systems, neural networks, genetic algorithms, fuzzy logic, cellular automata, chaotic systems, wavelets, complexity theory, anticipatory systems, and others. Many of these technologies (e.g., neural networks) date back several decades, whereas some (e.g., cellular automata) are still in the early development stages. Neural networks and fuzzy systems individually have reached a degree of maturity where they are each being applied to real-world situations. Researchers often utilize these two technologies in series, using one as the preprocessor or postprocessor for the other. Examples include the use of fuzzy inputs and outputs for neural networks, the use of neural networks to quantify the shape of a fuzzy membership function, and the use of individual neural networks for many sensors mounted on a machine to give individual diagnoses which are then fused using a fuzzy methodology. Although the results clearly suggest that such use of these technologies is synergistic and beneficial, there are indications that even greater benefits may be possible by the integration into a neurofuzzy technology with such concepts as the "fuzzy neuron" and the use of fuzzy logic functions to aggregate weighted inputs of a neuron. It is our perception that neurofuzzy technology (e.g., a technology that combines the feature extraction and modeling capabilities of the neural network with the representation capabilities of fuzzy systems) is at the stage that neural networks and fuzzy logic were at a decade ago.

There are other hybrid combinations of the different elements of soft computing that are also synergistic. Perhaps next in importance is the combination of genetic algorithms with neural networks and/or fuzzy systems. The ability to carry out near-global optimization on any problem for which an objective function can be defined is an incredibly powerful tool that can enhance the capabilities of any technology. The examples cited in this text only hint at the value of integrating genetic algorithms with other soft computing technologies. It is reasonable to expect that optimization of every step in a complex operation could significantly reduce computing time and improve results.

Expert systems offer a framework in which integration of the various soft computing technologies can be carried out. The ability to bring classical logic to bear on the integration process and to seek data and information from whatever sources are available offers the type of environment that could lead to a more flexible, user- and system-adaptive automation. Even more important is the use of fuzzy rules in expert systems so that interactions in complex systems can be represented.

In preparing the manuscript for this book, we were faced with the classical trade-off of breadth versus depth of coverage. We chose to cover the fundamentals of fuzzy systems and neural networks, and to a lesser extent genetic algorithms, in detail while using descriptive material to give perspective to the role of the various technologies involved. The material was originally intended for first-year graduate students, but additional information was included so that it would also be useful for a senior-level course and to practicing engineers. It is our hope that all of these groups will find this text to be useful and that the readers will be motivated to utilize this material in their work.

Many people contributed to the preparation of this manuscript, including many graduate students who used this material in draft form in class. Although it is not possible to acknowledge all of those who contributed, special recognition is due to individuals who read the manuscript in detail and offered constructive comments. Included in this special group, in alphabetical order, are Israel Alguindigue, R. C. Berkan, Mario Fontana, Wesley Hines, Vaclav Hojny, Andreas Ikonomopoulos, and Trent Powers. Graduate students whose research was described in this text are acknowledged by footnotes in the text. Earlier drafts of the manuscript have been used in short courses and seminars in the United States, Europe, and Japan. We are particularly grateful to Professors M. Kitamura and R. Kozma of Tohoku University in Japan, Dr. T. Washio of the Mitsubishi Research Institute, Professors S. Panas and J. Theoharis of Aristotle University in Greece, Professor Elias N. Houstis of Purdue University and Drs. Y. Shinohara, J. Shimazaki, K. Suzuki, K. Hayashi, S. Shinobu, H. Usui, Y. Fujii, K. Watanabe, Y. T. Suzudo, N. Ishikawa, and K. Nabeshima and Ms. S. Tobita (researchers and staff of the Control & AI Laboratory of JAERI in Japan). Their constructive criticism, suggestions, and intellectual support provided much of the inspiration and energy for completing this work. Special thanks are also due to the faculty and staff of the School of Nuclear Engineering at Purdue University and the Department of Nuclear Engineering at the University of Tennessee for their support. Two special individuals merit our gratitude for introducing us to the fields of fuzzy logic and neural networks, Professor M. Ragheb of the University of Illinois and Maureen Caudill of

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