Leszek Rutkowski

Computational Intelligence

METHODS AND TECHNIQUES

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Foreword

Publication of this book is a special event. This valuable title fills a serious gap in domestic science and technical literature. At the same time it introduces a reader to the most recent achievements in the quickly developing branch of knowledge which the computational intelligence has been for several years. The field, which is a subject of this book, is one of those important fields of science which enable to process information included in data and give their reasonable interpretation programmed by a user.

Recent decades have brought a stormy development of computer techniques and related computational methods. Together with their appearance and quick progress, theoretical and applied sciences developed as well, enabling the user to fully utilize newly created computational potential and to get knowledge out of increasing wealth of data. The development of computational intelligence is then strictly connected with the increase of available data as well as capabilities of their processing, mutually supportive factors. Without them the development of this field would be almost impossible, and its application practically marginal. That is why these techniques have especially developed in recent years.

The development of computational intelligence systems was inspired by observable and imitable aspects of intelligent activity of human being and nature. Nature when undertakes intelligent actions processes data in parallel regulating and adjusting these actions through feedback mechanisms. In such a system learning neural networks function. Another example can be optimization algorithms modeled based on natural selection processes or fuzzy logic systems reflecting vagueness, fuzziness, subjectivity or relativism of human being assessments.

Computational intelligence is a new branch of science and its development dates back to the 60s of the last century when the first algorithms of learning machines – forerunners of today's neural networks – were developed. Then, in the 70s foundations of set theory and fuzzy logic were created. In this early period of computational intelligence development genetic and evolutionary algorithms were introduced. In the 80s the bases for representation of knowledge using rough sets were also created. In recent years many hybrid techniques connecting learning systems with evolutionary and fuzzy ones were developed as well.

Developed theories of computational intelligence were quickly applied in many fields of engineering, data analysis, forecasting, in biomedicine and others. They are used in images and sounds processing and identifying, signals processing, multidimensional data visualization, steering of objects, analysis of lexicographic data, requesting systems in banking, diagnostic systems, expert systems and many other practical implementations.

The essence of the systems based on computational intelligence is to process and interpret data of various nature. These can be numerical, symbolic (e.g. language data of different degree of accuracy), binary, logical data or, for example, uncoded images read out directly on camera screen. The data can be formatted as numbers, that means single elements of vectors, as vectors or tables or as strings of elements or tables composed of them. They can also be composed of ordered sequences of elements or tables and contain elements described in a very inaccurate or even subjective manner.

The common feature of computational intelligence systems is that they process information in cases when presentation in the form of algorithms is difficult and they do it in connection with a symbolic representation of knowledge. These can be relations concerning an object known only based on a finite number of measurements of output and input state (activation). These can also be data binding the most probable diagnosis with a series of observed, often descriptive symptoms. In other cases these can be data characterizing sets in respect to some special features which are initially intangible to the user until they are derived from data and defined as dominant features. These systems have the capability to reconstruct behaviors observed in learning sequences, can form rules of inference and generalize knowledge in situations when they are expected to make prediction or to classify the object to one of previously observed categories.

This book is not only a valuable title on the publishing market, but is also a successful synthesis of computational intelligence methods in world literature. A special advantage of the book is that it contains many examples and illustrations of the methods described, which creates good opportunities to program the presented algorithms. This book should be recommended to engineers of various specialties, physicists, mathematicians, information technology specialists, economists and students of those or related specialties. It should give great satisfaction both to the author due to its

publishing and to many readers who will use the techniques described in the book to solve practical issues they are interested in.

July 18, 2007
Jacek M. Żurada
Past President of IEEE Computational Intelligence Society

Contents

1
Introduction

The origins of artificial intelligence can be traced back to early centuries, even to the times of ancient philosophers, especially if we consider the philosophical aspects of this field of science. Less distant in time is the first half of the 19th century when a professor of the University of Cambridge, Charles Babbage, came up with an idea of the so-called "analytical machine" which could not only perform arithmetic operations of a certain type but was also capable of performing operations according to pre-defined instructions. What played an essential role in that project was a punched card which one hundred years later turned out to be a very important element of communication between man and computer. In 1950 Alan Turing came up with a test, the purpose of which was to check whether a given program is intelligent. Soon afterwards a number of works appeared and research projects were carried out in order to understand the natural language and solving complex problems. The ambition of scholars was to create a universal system named "General Problem Solver", which was supposed to solve problems in many areas. The project ended in failure, yet while it was in progress, the researchers had an opportunity to explore the complexity of the issue of artificial intelligence. The 60s and 70s of the last century are characterized by complete dominance of the so-called symbolic approach to solving various issues of artificial intelligence. Thus, decision tree induction methods and methods of predicate logic were used as well as, to a certain extent, classical probabilistic methods, which, however, gained greater significance later on, upon the development of Bayesian networks. A characteristic feature of that time was departure from the use of numerical calculations to solve the problems of artificial intelligence. The

turning point in the development of artificial intelligence was publication of a book in 1986 in which Rumelhart and McClelland specified the method for learning of multilayer neural networks, which gave the possibility to solve the problems of, for instance, classifications that traditional methods could not handle. At the beginning of the nineties the concept of learning of neural networks was adopted to learning of fuzzy systems. In this way neuro-fuzzy structures were developed, moreover, a number of other combinations of neural networks, fuzzy systems and evolutionary algorithms were proposed. Today we have a separate branch of science defined in the English literature as Computational Intelligence. This term is understood as solving various problems of artificial intelligence with the use of computers to perform numerical calculations. Such computations are connected with application of the following techniques:

a) neural networks [242, 270],

b) fuzzy logic [94, 265],

c) evolutionary algorithms [57, 136],

d) rough sets [161, 163],

e) uncertain variables [18, 19],

f) probabilistic methods [1, 157].

Only those selected papers or monographs have been cited above, which present "soft computing" (soft techniques, [1, 108]). It must be emphasized that the subject of interest of computational intelligence covers not only individual techniques but also their various combinations [104]. There is an international society called IEEE Computational Intelligence Society, which organizes numerous conferences in the field of computational intelligence, moreover, it publishes three prestigious journals in this field, i.e. *IEEE Transactions on Neural Networks, IEEE Transactions on Fuzzy Systems and IEEE Transactions on Evolutionary Computation.* In Poland, the Polish section of this society exists. Methods of artificial intelligence and computational intelligence lie within the interests of the Polish Neural Networks Society, which organizes conferences called "Artificial Intelligence and Soft Computing" every two years. The purpose of those conferences is to integrate researchers who represent the traditional approach to the artificial intelligence methods and those who apply the methods of computational intelligence.

This book focuses on various techniques of computational intelligence, both single ones and those which form hybrid methods. Those techniques are today commonly applied to classical issues of artificial intelligence, e.g. to process speech and natural language, build expert systems and robots,

search for information as well as for the needs of learning by machines. Below are specified the main threads of this book.

In Chapter 2 we briefly present the selected issues concerning artificial intelligence, beginning with the historic Turing test and the issue of the "Chinese room". This chapter contains introductory information on expert systems, robotics, issues of speech and natural language processing as well as heuristic methods. The second part of the chapter focuses on the importance of cognitivistics, i.e. science which attempts to understand the nature of the mind. Further, the chapter introduces the reader to the issues of intelligence of ants and ant algorithms, the field of science called "artificial life" as well as intelligent computer programs known as bots. In the conclusion of this chapter, we quote the opinions of well-known scientists on the perspectives of artificial intelligence and formulate conclusions which reflect the author's views on this topic.

The subsequent three chapters present methods of knowledge representation using various techniques, namely the rough sets, type-1 fuzzy sets and type-2 fuzzy sets.

Chapter 3 presents basic information on the subject of rough sets. The issue of approximation of set and family of sets is discussed therein. The second part of the chapter presents the issues of decision tables, and subsequently the LERS program is used to generate a rule base. The chapter in question, like the two subsequent ones, is richly illustrated with examples which make it easier for the reader to understand various definitions.

Chapter 4 presents basic terms and definitions of fuzzy sets theory. Then it discusses the issue of reasoning, i.e. reasoning on the basis of fuzzy antecedents. Moreover, the reader is introduced to the method for construction of fuzzy inference systems. The second part of the chapter contains numerous examples of applications of fuzzy sets in the issues of forecasting, planning and decision-making.

In Chapter 5, basic definitions concerning type-2 fuzzy sets are presented, operations on those sets are discussed, and subsequently type-2 fuzzy relations are discussed as well. Much attention has been given to the type-reduction method, i.e. a method of transformation of type-2 fuzzy sets into type-1 fuzzy sets. The last part of the chapter explains to the reader the issue of designing type-2 fuzzy inference systems.

Chapter 6 discusses artificial neural networks. This chapter first presents various mathematical models of a single neuron. Next the structure and functioning of multilayer neural networks are discussed. A number of algorithms for learning of those networks have been presented and the issue of choosing their architecture is given particular attention. In the subsequent paragraphs the reader is introduced to the idea of neural networks with feedback. The structure and functioning of the Hopfield, Hamming, Elman, RTRN and BAM networks are discussed. In the second part of the chapter we present the issue of self-organizing neural networks with competitive learning, ART networks, radial-basis function networks and probabilistic neural networks.

Chapter 7 discusses the family of evolutionary algorithms, in particular the classical genetic algorithm, evolutionary strategies and genetic programming. We also present advanced techniques used in evolutionary algorithms. The second part of the chapter discusses connections between evolutionary techniques and neural networks and fuzzy systems.

Chapter 8 presents various methods of data partitioning and algorithms of automatic data clustering. The definitions of hard, fuzzy and possibilistic partitions are provided. Subsequently distance measures applied in clustering methods are presented, which is followed by the discussion of the most popular data clustering algorithms, i.e. HCM algorithm, FCM algorithm, PCM algorithm, Gustafson-Kessel algorithm and FMLE algorithm. This chapter is finished with a presentation of known data clustering validity measures.

In Chapter 9 we present various neuro-fuzzy structures. Those structures are a multilayer (network) representation of a classical fuzzy system. To construct them, the Mamdani type inference and the logical-type inference were applied. Moreover, the so-called Takagi-Sugeno schema is discussed, where the consequents of rules are not fuzzy in nature but are functions of input variables. A characteristic feature of all structures is the possibility to enter weights reflecting the importance of both particular linguistic values in the antecedents of fuzzy rules and weights reflecting the importance of the entire rules. The concept of weighted triangular norms presented in Chapter 4 was used to build those structures. Those norms do not meet the boundary conditions of a classical t-norm and t-conorm, as the commonly applied Mamdani type inference rule does not meet the conditions of logical implication. This chapter illustrates that the application of weighted triangular norms leads to the construction of neuro-fuzzy structures characterized by a very low system operation error. In the second part of the chapter we present the algorithms for learning of all structures, and then we solve the issue of designing neuro-fuzzy systems which are characterized by a compromise between the system operation error and the number of parameters describing this system.

Chapter 10 presents the concepts of the so-called flexible neuro-fuzzy systems. Their characteristic feature is the possibility to find a method of inference (of Mamdani or logical type) as a result of the learning process. The execution of such systems will be possible thanks to specially constructed adjustable triangular norms which are presented in this chapter. Moreover, the following concepts have been used to build the neuro-fuzzy systems: the concept of soft triangular norms, parameterized triangular norms as well as weights used previously in Chapter 9 and describing the importance of particular rules and premises in those rules.

Some of the results presented in this book are based on the research conducted within the Professorial Grant (2005-2008) supported by the Foundation for Polish Science and Special Research Project (2006-2009) supported by Polish Ministry of Science and Higher Education.

The book is the result of, among other things, lectures given by its author in the last few years to graduate students of Politechnika Częstochowska and Academy of Humanities and Economics in Łódź, as well as to PhD students of the Systems Research Institute of the Polish Academy of Science.

The book is also the outcome of cooperation with colleagues from the Department of Computer Engineering of Politechnika Częstochowska, who learned the secrets of computational intelligence as my students back in their fourth year of studies. Thus, I would like to give heartfelt thanks for support to Krzysztof Cpałka, PhD. Eng., Robert Nowicki, PhD Eng., Rafał Scherer, PhD Eng., and Janusz Starczewski, PhD Eng. Moreover, I would like to thank the representatives of a slightly younger generation of scientists at the Department of Computer Engineering, namely Marcin Gabryel, PhD. Eng., Marcin Korytkowski, PhD. Eng., Agata Pokropińska, PhD. Eng., Łukasz Bartczuk, MSc. Eng. and Piotr Dziwiński, MSc. Eng. I also sincerely thank Ms Renata Marciniak, MSc., who took the trouble of preparing part of the drawings.

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