Fuzzy and Neuro-Fuzzy Intelligent Systems

Studies in Fuzziness and Soft Computing

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continued on page 195

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and 16 Tables

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To all who fought
for democratic transformations
in Poland after World War II

Preface

Intelligence systems. We perform routine tasks on a daily basis, as for example:

- recognition of faces of persons (also faces not seen for many years),
- identification of dangerous situations during car driving,
- deciding to buy or sell stock,
- reading hand-written symbols,
- discriminating between vines made from Sauvignon Blanc, Syrah or Merlot grapes, and others.

Human experts carry out the following:

- diagnosing diseases,
- localizing faults in electronic circuits,
- optimal moves in chess games.

It is possible to design artificial systems to replace or "duplicate" the human expert. There are many possible definitions of intelligence systems. One of them is that: an intelligence system is a system able to make decisions that would be regarded as intelligent if they were observed in humans. Intelligence systems adapt themselves using some example situations (inputs of a system) and their correct decisions (system's output). The system after this learning phase can make decisions automatically for future situations. This system can also perform tasks difficult or impossible to do for humans, as for example: compression of signals and digital channel equalization.

Fuzzy sets and systems. Before Prof. L.A.Zadeh introduced fuzzy sets, he worked on linear systems theory, and his papers and books are still the basis for modern control theory. In the early 60s, he concluded that classical theories had put too much emphasis on precision and could not describe complex systems. This can be formulated in the so-called principle of incompatibility: "...as the complexity of a system increases, our ability to make precision and yet significant statements about its behavior diminishes until a threshold is reached beyond which precise and significance (or relevance) become almost mutually exclusive characteristics." Succinctly this principle may be written as: "The closer one looks at a real-world problem, the fuzzier becomes its solution."

The real world is too complex and complicated to be described precisely. A reasonable model can be obtained using "fuzzy approximation". This alternative to classical approach is based on the observation that humans think using linguistic terms such as "small" or "very large" and others rather than numbers. To describe this concept in a natural language, Zadeh used fuzzy sets introduced by himself in 1965. The essence of fuzzy systems are conditional if-then statements, which use fuzzy sets as linguistic terms in premise and conclusion parts. A collection of these fuzzy if-then statements formulates the rulebase. This rulebase can be determined from human expert knowledge or alternatively generated from observed data (examples) automatically. The main advantage of such fuzzy systems is the easiness to interpret knowledge in the rulebase.

Artificial neural networks. Since humans can perform many tasks presented at the beginning of this preface better than the best machines, human brain has been of great interest for engineers. This led to perceptron in the late 50s and to artificial neural networks (ANNs) in mid 80s. ANNs were originally developed with a view to modeling learning and processing information in the brain. For the purpose of this book, the ANNs is an important tool in the arsenal of machine-learning techniques, rather than model of the brain. Prof. S. Haykin proposed the following definition of ANNs: "A neural network is a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experiential knowledge and making it available for use. It resembles the brain in two respects:
1). Knowledge is acquired by the network from its environment through a learning process,
2). Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge." In practice the majority of ANNs works on single-processor computers.

The most common mode of learning for both humans and ANNs is supervised. In this case we have some situations (examples) and correct decisions, which formulate a training set. If we have only situations without correct decisions, then ANNs can perform unsupervised learning, which is often called clustering. In this mode ANNs search for structures of data. Both types of learning will be used in this book for the construction of neuro-fuzzy systems.

Neuro-fuzzy systems. In most fuzzy systems fuzzy if-then rules were obtained from the human expert. However, this method of knowledge acquisition has great disadvantages: not every expert can and/or wants to share his knowledge. Artificial neural networks were incorporated into fuzzy systems forming the so-called neuro-fuzzy systems, which can acquire knowledge automatically by learning algorithms of neural networks. The neuro-fuzzy systems have advantages over fuzzy systems, i.e. acquired knowledge is easy to understand (are more meaningful) to humans. Like in neural networks knowledge is saved in connection weights, but can be easily interpreted as fuzzy if-then rules.

The most frequently used neural networks in neuro-fuzzy systems are radial basis function networks. Their popularity is due to the simplicity of structure, well-established theoretical basis and faster learning than in other types of artificial neural networks.

If the number of input variables is large then it is very difficult to apply neuro-fuzzy systems, because the input space is divided into a very large number of fuzzy regions in which one if-then rule operates dominantly (Bellman's course of dimensionality). The neuro-fuzzy system can be viewed as a mixture of local experts (rules operate dominantly in each region). To determine these regions clustering method (unsupervised networks) for input or input-output space is often used. Clustering has been employed for initialization of unknown values of neuro-fuzzy system parameters such as: a number of fuzzy if-then rules and membership function of linguistic terms from premise parts of these rules. In the next step these parameters are updated using gradient and least squares optimization methods. Recently global optimization methods are frequently used to update neuro-fuzzy system parameters. Connection of fuzzy systems, artificial neural networks, clustering and optimization methods is usually called soft computing systems.

Prerequisites and audience. The prerequisites for the book are basic calculus and algebra, at the level of an undergraduate course. Any prior knowledge of the human nervous system and nervous cells is of course helpful, but not required. It is assumed that the reader has a background in Matlab® system (produced and distributed by MathWorks, Inc.). The neuro-fuzzy system presented in this book was implemented as Matlab m-files in Appendix A included by the end of Chapter 6. Databases used in book for neuro-fuzzy system tests can be easy obtained via Internet. URLs are available in Chapter 7.

The book is aimed for use by the researcher who wants to learn basics and advanced concepts of neuro-fuzzy systems. It is also suitable for students of Computer Sciences, Electronics and Automatic Control. This book is also intended for use by biologists, economists and physicians. It is sufficiently simple for the reader to be able to implement the algorithms described in the book, or adapt them to solve particular problems.

Generals outline of the book. The book is divided into seven chapters. Chapter 1 provides an overview of fuzzy sets theory. The basic notions and terminology of this theory is presented: definition of fuzzy sets, basic types of membership functions, operations on fuzzy sets, fuzzy relations, cylindrical extension, projection of fuzzy sets and linguistic variable.

Chapter 2 is the most important theoretical chapter, since it lays the foundations for approximate reasoning principles. Different interpretations and an axiomatic definition of fuzzy implication are shown. In this chapter we also present the following: basic fuzzy rule of inference, composition and individual rule- based inference and approximate reasoning with singletons. The most important outcome of Chapter 2 is the presentation of specific equivalence of inference results using logical and conjunctive interpretations of if-then rules.

Chapter 3 focuses on an overview of basic topologies of artificial neural networks, main methods of learning in ANNs including back-propagation and its modifications. Gradient based and global optimization methods are also shown as well as optimization of the parameters which linearly depend on ANNs output.

In Chapter 4 unsupervised neural networks and clustering methods are recalled. Self-organizing feature map, vector quantization and its connection with clustering is presented. Moreover, this chapter contains the basic classical (non-fuzzy) algorithms for clustering, foundations for fuzzy clustering, possibilistic and conditional as well as cluster validity methods.

Chapter 5 is a warm-up chapter, to illustrate fuzzy systems. It presents the basic structure of fuzzy systems, Mamdani's, Takagi-Sugeno-Kang's fuzzy systems, and a system with parameterized consequents in fuzzy if-then rules. This chapter together with Chapter 6 forms the core of the book.

Chapter 6 contains an overview of neuro-fuzzy systems known from literature and **A**rtificial **N**eural **N**etwork **B**ased on **F**uzzy **I**nference **S**ystem (ANNBFIS) with parameterized consequents. A hybrid method of learning ANNBFIS, which is a connection of clustering, gradient and least squares methods, a proposal of classifier based on ANNBFIS and Matlab® m-files implementation of ANNBFIS are also shown.

Chapter 7 contains a selected list of applications of ANNBFIS to: chaotic time series prediction, classification, system identification, compression of signals, control and communication.

What is new and what is omitted in this book. In various sections of the book new, unpublished material was introduced or published (accepted to publish) but presented from a somewhat new point of view. In Chapter 2 a specific type of equivalence of inference results based on conjunctive (minimum, product) and fuzzy implication interpretations of fuzzy if-then rules is presented. This equivalence is based on new defuzzification methods. In Chapter 4 a new generalized weighted conditional fuzzy c-means clustering method is introduced. In the same chapter a new cluster validity index is presented. In Chapter 5 fuzzy inference system with parameterized fuzzy sets in consequence of fuzzy if-then rules is introduced. A special case where localization of fuzzy sets in consequence is determined as a linear combination of input singletons is described for selected fuzzy implications. This fuzzy inference system is used in Chapter 6 to construct Artificial neural network based on fuzzy inference system (ANNBFIS). The learning method which is a connection of clustering, gradient, least squares and some heuristic methods is used. A proposal of the application of ANNBFIS to classification with proof of convergence is also presented. At the end of this chapter deterministic annealing to ANNBFIS learning is proposed.

The material for the book had to be selected on the basis on our individual choice. Many important topics had to be omitted in order to stay within the assumed number of pages. We focused on algorithms for fuzzy if-then rule extraction from numerical data, so a fuzzy system with singletons as inputs was presented with special attention to detail. At the end of each chapter references with complementary interpretations can be found.

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Jacek Łęski
Gliwice, December 1999

Contents