Chapter 1
Introduction

Systems can be represented by mathematical models of many different forms, such as algebraic equations, differential or integral equations, finite state machines, Petri nets, rules, etc. They are used particularly in the natural sciences and engineering disciplines such as physics, biology, electrical and computer engineering, in the social sciences such as economics or sociology. Engineers, computer scientists, physicists and economists use mathematical models most extensively. A mathematical model should be a representation of the essential aspects of an existing system (or a system to be constructed). This model should express the knowledge of that system in usable form [45].

Fuzzy systems theory enables us to utilize qualitative, linguistic information about a system to construct a mathematical model for it [132]. For many real-life systems, which are highly complex and inherently nonlinear, conventional approaches to modeling are not easy to apply, whereas the fuzzy approach might be a very helpful alternative. The modeling framework considered in this book is based on the models which describe relationships between variables by means of fuzzy "If-then" rules. Such models have one of two general structures: Mamdani or Takagi-Sugeno (TS). The difference between them is the construction of the rule consequents. In the former one, the consequents are linguistic (fuzzy sets), whereas the latter one employs crisp functions (or simply constants). Our considerations will be restricted to the Takagi-Sugeno models with the simplest fuzzy sets for the input variables.

Fuzzy models can be seen as rule-based systems suitable for formalizing the knowledge of experts. At the same time they are flexible mathematical structures which can represent complex nonlinear mappings. They integrate the logical processing of information with function approximation. Rule-based systems are not restricted to areas requiring human expertise and knowledge; they can be obtained from empirical data, as well. Methods for constructing fuzzy models from input-output data should not be limited to the best approximation of the data set only, but also and more importantly, to extract knowledge from training data in the form of the fuzzy rules. The rules should be easily understood and interpreted (see e.g. [12]). However, the

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interpretability of fuzzy systems has not received much attention in the field of fuzzy modeling until now.

Fuzzy control is easy to learn and easy to apply, since it is close to human intuition. For this reason, it has been successfully applied to a variety of industrial processes and consumer products such as chemical reactors, cement kilns, vacuum cleaners, washing machines, autofocusing cameras, air conditioners, robots, voice-controlled robot helicopters, elevator systems and so on. However, we still need efficient analytical analysis and design methods to enable our deep understanding of fuzzy systems in the context of conventional modeling methods and control tools. Furthermore, we need systematic and unified approaches to design highly interpretable fuzzy models for the dynamical plants, the fuzzy controllers and other systems which are used in the engineering practice. Unfortunately, despite much research, such approaches seem to be only beginning to emerge. The main difficulty in the mathematical analysis of fuzzy models is that they are inherently nonlinear and, therefore, classical control theory with its emphasis on linear systems is difficult to apply or cannot be applied at all.

It should be added that the existing fuzzy models in the form of fuzzy "If-then" rules are not free from drawbacks. The curse of dimensionality problem of the rule-based systems is one of them. What is more, the fuzzy systems are mostly treated as magic black boxes with little analytical understanding and explanation [206]. Furthermore, there are no analytical results concerning quality of the closed-loop fuzzy control systems; practically all 'proofs' from the field of fuzzy control have been made by simulations, which is not always accepted by the scientific community. Finally, engineers need sufficiently clear and well justified methods for modeling and control which can be directly applied in practice. Such opinion and the above mentioned questions were the main motivation for writing this book.