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FUZZY LOGIC SYSTEMS

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This article gives a brief description of fuzzy logic systems, comparative analysis of Defuzzification methods used to build artificial intelligence. The description of the basic principles, rules and operations for working with fuzzy sets is introduced.

Fuzzy systems have been successfully applied as a paradigm, demonstrating the use of linguistic information in the design of systems. Industrial design is involved in the process of monitoring and improving products, for this purpose forecasting and time series analysis are used. In production control and planning fuzzy systems are the subject of research and implementation. For example, applications of fuzzy constraint removal in planning [1], fuzzy approach to dispatching rules in schedules [2].

The process of a fuzzy system design is described as a process of articulating commonsense knowledge by using terms, creating fuzzy rules and numerically defined membership functions for them, and applying a fuzzy inference method. The notion of a fuzzy set was introduced first by Lotfi Zadeh in 1965, who later developed many of the methods of fuzzy logic based on this simple notion. It took a couple of decades for the rationale of fuzzy sets to be understood and applied by other scientists [3].

The traditional way of representing elements u of a set A is through the characteristic function: $\mu A(u) = 1$, if u is an element of the set A, and $\mu A(u) = 0$, if u is not an element of the set A, that is, an object either belongs or does not belong to a given set. In fuzzy sets an object can belong to a set partially. The degree of membership is defined through a generalized characteristic function called membership function.

The values of the membership function are real numbers in the interval [0, 1], where 0 means that the object is not a member of the set and 1 means that it belongs entirely. Each value of the function is called a membership degree. One way of defining a membership function is through an analog function.

Ordinary sets are a special case of fuzzy sets when two membership degrees only, 0 and 1, are used, and crisp borders between the sets are defined. All definitions, proofs, and theorems that apply to fuzzy sets must also be valid in the case when the fuzziness becomes zero, that is, when the fuzzy set turns into an ordinary one.

An analog-function representation of membership functions is used to represent some operations with fuzzy sets. The following operations over two fuzzy sets A and B defined over the same universe U are the most common in fuzzy theory: Union, $A \cup B$, Intersection, $A \cap B$, Equality, $A = B$.

One of the most important steps toward using fuzzy logic and fuzzy systems for problem-solving is representing the problem in fuzzy terms. This process is called conceptualization in fuzzy terms. We often use linguistic terms in the process of identification and specification of a problem, or in the process of articulating heuristic rules [4].

The term linguistic variable is a variable which takes fuzzy values and has a linguistic meaning. The process of representing a linguistic variable into a set of linguistic values is called fuzzy quantization. Choosing the number and the form of all the fuzzy labels that represent a fuzzy variable is a crucial point for a fuzzy system. If we have defined the fuzzy-quantizing labels, for example, "small," "medium," or "large," we can represent any particular data item as a set of membership degrees to the fuzzy labels. Fuzzy discretization does not lead to loss of information if the fuzzy labels are correctly chosen.

Fuzzy values defined by standard membership functions have some useful properties when used in fuzzy rules. Choosing a standard type of membership function, when not given or known a priori, resembles choosing the gaussian probability distribution for the conditional probability in the Bayes's theorem.

Fuzzy quantization is possible not only on numerical variables but also on qualitative variables like "truthfulness of events." Fuzzy qualifiers give a fuzzy evaluation of the truthfulness of an event. Typical fuzzy qualifiers are "very true," "more or less true," and ''not true,".

The biggest restriction in classic propositional and predicate logic is the fact that the propositions can have their truth-values as either True or False. This restriction has its assets as well as its drawbacks. The main asset is that the decision obtained is exact and precise. The main drawback, however, is that it cannot reflect the enormous diversity of the real world, which is analog and not digital. The truth value of a proposition in classic logic cannot be unknown, for example.

In order to overcome this limitation of classic logic, multivalued logic has been developed. The truth of a proposition is represented by a set *T* of *n* possible truth-values, when *n*-valued logic is considered. For the three-valued logic, *T = {0,0.5,1}*. There are a huge number of theories, formulated on the basis of the multivalued nature of truth. Fuzzy logic can be considered an extension of the multivalued logic.

Fuzzification is the process of finding the membership degrees μA1(x'1) and μA2(x'2) to which input data x'1 and x'2 belong to the fuzzy sets A1 and A2 in the antecedent part of a fuzzy rule. Through fuzzification the degrees to which input data match the condition elements in a rule are calculated. When fuzzy input data are used, such a degree can be represented by the similarity between the input membership function and the condition element.

Defuzzification is the process of converting information from the space of universal fuzzy data into the space of output operational values. In 1996, in scope of the Intelligent Control Term Project Papers, a study was conducted of the characteristics of various defuzzification methods conducted by Won-Kyung Song and Jong-Pil Lee [4]. Conversion of fuzzy sets to numerical values is impossible without losing part of the information contained in it. Many dephasing methods have been developed, but most of them have similar problems. And there is no single rule that helps to choose a method for solving a particular problem. The authors considered 14 methods of defuzzification:

Comparison of defuzzification methods for standard membership functions is presented in table 1.

Table 1. – Modern methods of defuzzyfication and its characteristics

	Continui-ty	Disambiguity	Plausibility	Comp. Complexity	Weight Counting	Confidence Level Loss	Discrete Version
Center of Gravity	Yes	Yes	No	Bad	No	Yes	Yes
Center of Sums	Yes	Yes	No	Bad	Yes	Yes	Yes
Mean of Maxima	No	Yes	No	Good	No	No	Yes
Center of Maxima	No	Yes	No	Good	No	No	Yes
First of Maxima	No	Yes	No	Good	No	No	Yes
Last of Maxima	No	Yes	No	Good	No	No	Yes
Center of Area	Yes	Yes	No	Bad	No	Yes	Yes
Center of Largest Area	No	No	Yes	Bad	No	Yes	Yes
Height	Yes	Yes	No	Good	Yes	Yes	Yes
Maximal Height	No	No	Yes	Good	No	No	Yes
BADD	Yes	Yes	No	Bad`	No	Yes	Yes
SLIDE	Yes	Yes	No	Bad	Yes	Yes	Yes
M-SLIDE	Yes	Yes	No	Bad	Yes	Yes	Yes
Saade's Method	Yes	Yes	Yes	Bad	Yes	Yes	No

Conclusion. In this article we have examined the basic principles of fuzzy logic, the main ways to build fuzzy systems. A brief description of the basic concepts and terms is given - fuzzy set, membership functions, classifiers, quantization. The stages of fuzzification and de-fuzzification were studied, and the methods of de-fuzzification and their characteristics were compared.

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