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Review article

A review on type-2 fuzzy logic applications in clustering, classification and pattern recognition

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ABSTRACT

In this paper a review of type-2 fuzzy logic applications in pattern recognition, classification and clustering problems is presented. Recently, type-2 fuzzy logic has gained popularity in a wide range of applications due to its ability to handle higher degrees of uncertainty. In particular, there have been recent applications of type-2 fuzzy logic in the fields of pattern recognition, classification and clustering, where it has helped improving results over type-1 fuzzy logic. In this paper a concise and representative review of the most successful applications of type-2 fuzzy logic in these fields is presented. At the moment, most of the applications in this review use interval type-2 fuzzy logic, which is easier to handle and less computational expensive than generalized type-2 fuzzy logic.

Contents

1. Introduction

The concept of information is inherently associated with the concept of uncertainty. The most fundamental aspect of this connection is that the uncertainty involved in any problem-solving situation is a result of some information deficiency, which may be incomplete, imprecise, fragmentary, not fully reliable, vague, contradictory, or deficient in some other way. Uncertainty can be viewed as an attribute of information. The general framework of fuzzy reasoning allows handling much of this uncertainty and fuzzy systems can use type-1 fuzzy sets, which represent uncertainty by numbers in the range [0, 1]. When an entity is uncertain, like a measurement, it is difficult to determine its exact membership value, and of course type-1 fuzzy sets make more sense than sets. However, it is not reasonable to use an accurate membership function for something uncertain, so in this case what we is needed is another type of fuzzy sets, those which are able to handle these uncertainties, the so called type-2 fuzzy sets [14]. The amount of uncertainty in a system can be reduced by using type-2 fuzzy logic because this logic offers better capabilities to handle linguistic uncertainties by modeling vagueness and unreliability of information [5].

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Type-2 fuzzy models have emerged as an interesting generalization of fuzzy models based upon type-1 fuzzy sets. There have been a number of claims put forward as to the relevance of type-2 fuzzy sets being regarded as generic building constructs of fuzzy models [25]. Likewise, there is a record of some experimental evidence showing some improvements in terms of accuracy of fuzzy models of type-2 over their type-1 counterparts [5]. Unfortunately, no systematic and comprehensive design framework has been provided and while improvements over type-1 fuzzy models have been evidenced, it is not clear whether this effect could always be expected. Furthermore, it is not demonstrated whether the improvement is substantial enough and fully legitimized given the substantial optimization overhead associated with the design of this category of models. At this moment, most of type-2 fuzzy systems have been implemented as interval type-2 fuzzy systems, which are simpler and computationally less expensive. Basically, an interval type-2 fuzzy systems uses interval type-2 fuzzy sets, which assume a constant secondary membership degree and thus avoiding evaluating multiple degree values. There have been a lot of applications of interval type-2 fuzzy logic in intelligent control, pattern recognition, time series prediction, and others [5,14,25,26]. However, in this paper we will concentrate on applications in clustering, classification and pattern recognition.

The rest of the paper is structured as follows. Section 2 offers a brief overview of the basic concepts of type-2 fuzzy systems. Section 3 provides a concise review of type-2 fuzzy logic applications in clustering and classification. Section 4 presents a review of type-2 fuzzy logic applications in image processing and pattern recognition. Section 5 presents the future trend and direction in the area. Finally, Section 6 presents the conclusions.

2. Type-2 fuzzy systems

In this section, a brief overview of type-2 fuzzy systems is presented. This overview is intended to provide the basic concepts needed to understand the methods and algorithms presented later in the paper [10,13].

The structure of the type-2 fuzzy rules is the same as for the type-1 case because the distinction between type-2 and type-1 is associated with the nature of the membership functions [14]. Hence, the only difference is that now some or all the fuzzy sets involved in the rules are of type-2. In a type-1 fuzzy system, where the output sets are type-1 fuzzy sets, we perform defuzzification in order to get a number, which is in some sense a crisp (type-0) representative of the combined output sets. In the type-2 case, the output sets are of type-2; so we have to use extended versions of type-1 defuzzification methods [5].

If for a type-1 membership function, we blur it to the left and to the right, as illustrated in Fig. 1, then a type-2 membership function is produced. In this case, for a specific value x', the membership function (u'), takes on different values, which are not all weighted the same, so we can assign membership grades to all of those points.

By doing this for all $x \in X$, we form a three-dimensional membership function – a type-2 membership function – that characterizes a type-2 fuzzy set [13]. A type-2 fuzzy set $\tilde{A}$, is characterized by the membership function:

$$\tilde{A} = \{((x, u), \mu_{\tilde{A}}(x, u)) | \forall x \in X, \forall u \in J_x \subseteq [0, 1]\} \quad (1)$$

in which $0 \le \mu_{\tilde{A}}(x, u) \le 1$. In fact $J_x \subseteq [0, 1]$ represents the primary membership of x, and $\mu_{\tilde{A}}(x, u)$ is a type-1 fuzzy set known as the secondary set. Hence, a type-2 membership grade can be any subset in $[0, 1]$, the primary membership, and corresponding to each primary membership, there is a secondary membership (which can also be in $[0, 1]$) that defines the possibilities for the primary membership. Uncertainty is represented by a region, which is called the

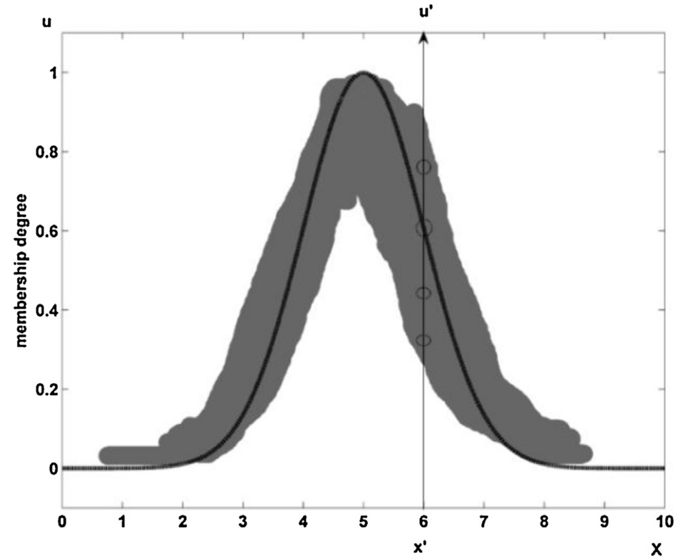

Fig. 1. Type-2 membership function as a blurred type-1 membership function.

footprint of uncertainty (FOU). When $\mu_{\tilde{A}}(x, u) = 1, \forall u \in J_x \subseteq [0, 1]$ we have an interval type-2 membership function, as shown in Fig. 2. The uniform shading for the FOU represents the entire interval type-2 fuzzy set and it can be described in terms of an upper membership function $\bar{\mu}_{\tilde{A}}(x)$ and a lower membership function $\underline{\mu}_{\tilde{A}}(x)$.

An FLS described using at least one type-2 fuzzy set is called a type-2 FLS. Type-1 FLSs are unable to directly handle rule uncertainties, because they use type-1 fuzzy sets that are certain, which are fully described by single numeric values. On the other hand, type-2 FLSs, are useful in circumstances where it is difficult to determine an exact numeric membership function, and there are measurement uncertainties.

A type-2 FLS is characterized by IF-THEN rules, where their antecedent or consequent sets are now of type-2. Type-2 FLSs, can be used when the circumstances are too uncertain to determine exact membership grades such as when the training data is affected by noise. Similarly, to the type-1 FLS, a type-2 FLS includes a fuzzifier, a rule base, fuzzy inference engine, and an output processor, as we can see in Fig. 3 (in this case, a fuzzy system with two inputs and

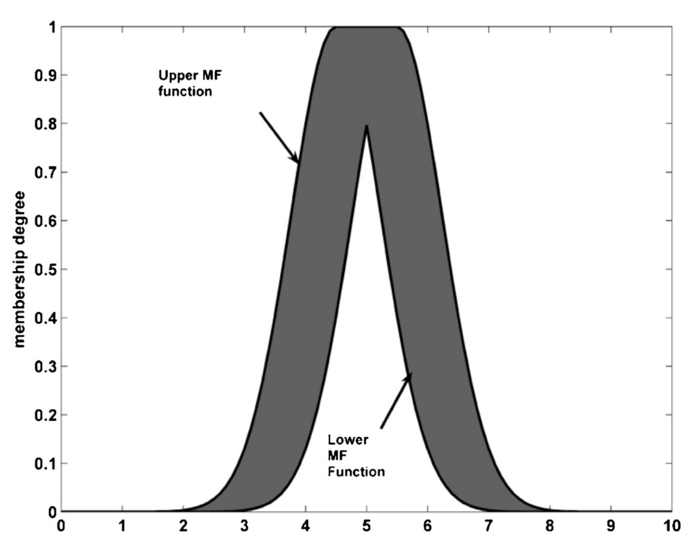

Fig. 2. Interval type-2 membership function.