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A Survey on the Design of Fuzzy Classifiers Using Multi-Objective Evolutionary Algorithms

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Abstract: ***Fuzzy systems have been used in many fields like data mining, regression, patter recognition, classification and control due to their property of handling uncertainty and explaining the property of complex system without involving a specific mathematical model. Fuzzy rule based systems (FRBS) or fuzzy rule based classifiers (particularly designed for classification purpose) are basically the fuzzy systems which consist a set of logical fuzzy rules and These FRBS are annex of traditional rule based systems, because they deal with "If-then" rules. During the design of any fuzzy systems, there are two main features, Interpretability and accuracy which are conflicting with each other i.e. Improvement in any of these two features causes the decrement in another one. This condition is called Interpretability –Accuracy Trade-off. To handle such kind of situation Multi Objective Evolutionary Algorithms are used to design fuzzy systems. This paper is a review of different design approaches of fuzzy systems and various methods to analyze the I-A tradeoffs in the design of fuzzy classifiers. Also various techniques for assessment of accuracy and interpretability have been discussed.***

Keywords: I-A tradeoff, Fuzzy Rule Based Systems (FRBS), Multi Objective Genetic Algorithms (MOGA), Multi Objective Evolutionary Algorithms (MOEA).

1. Introduction

A set of fuzzy If-then rules that maps inputs to outputs is known as fuzzy model. A fuzzy model basically consist three components: a rule base- set of fuzzy rules, a database or dictionary-for specifying the membership functions of fuzzy rules, and a reasoning methodology-for performing the implication process upon a given condition and the rules to obtain a realistic solution. [1]

In the area of pattern classification and recognition [2] [3] use of fuzzy rule based systems (FRBSs) represents an effective development. These FRBSs are generally well known as Fuzzy Rule Based Classifiers (FRBCs). [4]

During design of any fuzzy systems, there are two major objectives: Increment in the accuracy and the interpretability of fuzzy rule based system. These two objectives are usually conflicting in nature. For example, complex fuzzy rule-based systems with more accuracy are not interpretable. Very simple fuzzy rule-based systems with more interpretability are likely to be incorrect [5].

Interpretability is defined as the capacity of a system that permits to recognize its behavior/property by analyzing its functions/rule base. Whereas the capacity of the system to authentically represent the real system is known as "Accuracy". Interpretability and Accuracy are two major features during the design of fuzzy system. Improvement in any of these two features causes the decrement in another one. This is called Interpretability ~Accuracy Tradeoff (I-A Tradeoff).

Interpretability is classified into two categories, Complexity based Interpretability (CBI) having objective to reduce the complexity of the generated system usually computed by number of rules, labels, variable per rule etc and Semantics based Interpretability (SBI) to conserve the semantics linked with Membership Functions (MFs). It depends on methods of applying constraints on the features like distinguishably, coverage etc or on membership functions.

The design of fuzzy systems taking into consideration two objectives Interpretability and Accuracy can be defined as two objective problem of optimization and such kind of problem have been solved by Multi –Objective Evolutionary Algorithms(MOEAs). The fuzzy systems generated by MOEA are denoted by term Multi–Objective Evolutionary Fuzzy Systems (MOEFS)[6][7].

Evolutionary Multi objective Optimization has been discussed in [8], Context Adaptation and Hierarchical Fuzzy Modeling have been explored in [9] [10] respectively and many other approaches and methods related to rules, rule bases, fuzzy partitions, membership functions etc are used to maintain a good trade off in the design of fuzzy systems. This paper is compiled into five another divisions. In division 2 fuzzy rule based classifiers have been discussed. Division 3 contains the details about I-A tradeoff, in division 4 issues related to multi objective algorithms have been discussed, division 5 is about various methodologies related to design attributes of a fuzzy system and division 6 is conclusion and future scope.

2. Fuzzy Rule-Based Classifiers

Based on the object description, a class label to an object is generally assigned by a classifier. It is also said that the classifier predicts the class label. Classification belongs to the general application field of pattern recognition and machine learning.

The classification of any input pattern into the class depends on the measured maximum degree of association corresponding to the rule for that pattern. In the case of similarities, the random classification of pattern shall be done.

The objectives of fuzzy systems like Accuracy and interpretability depends on the maximum association degree of Pattern classified into a class corresponding to high dimensional rule base. During the design of fuzzy classifier, interpretability and accuracy are two main objectives which are opposite in nature i.e. one objective can be enhanced on the cost of another one. This condition is well known as I-A tradeoff.

In [52], problem of high dimensionality has been addressed with fuzzy clustering approach. A fuzzy classifier has been developed using MATLAB with evolutionary multi-objective optimization.

3. Interpretability-Accuracy Tradeoff

Interpretability is primarily focused in the Mamdani Fuzzy Systems (Linguistic Fuzzy modeling) and Accuracy is concentrated in Takagi-Sugeno-Kang Fuzzy Systems (Precise Fuzzy Modeling) [11]. A major research issue in area of developing evolutionary Fuzzy systems is to obtain many fuzzy systems on the arc of I-A tradeoff and out of that find out any one having a fine trade off.

The improvement of the objectives either Interpretability or Accuracy depends upon requirement of modeling, some modeling applications instead of focusing separately on accuracy or interpretability; require an optimum level of interpretability and accuracy. This will direct to I-A trade off. In [50], a survey on the I-A trade-off has been carried out in Evolutionary Multi-Objective Fuzzy Systems. This paper introduces the basic concepts of Evolutionary Multi-Objective Fuzzy Systems.

If complexity of any system is High then the Accuracy of system will be High and Interpretability will be Low and If the complexity of any system is Low then the Accuracy of system will be Low and Interpretability will be High. This condition is known as I-A tradeoff. [12] To deal with such tradeoff situation, multi objective optimization algorithms are used in the fuzzy systems design which is discussed in next section of this paper.

A classification of various issues related to multi objective optimization, taking in to account I-A trade off has been discussed in [13].

The two objective based approaches for I-A using EMO having major focus of feature selection and granularity learning is discussed in [14] and the accuracy of classification and number of rules is discussed in [15].

During Handling I-A tradeoff using EMO, tuning of membership functions and rule selection is a very important area discussed in [16-26]. Sum of antecedent conditions and root mean squared error [27], Fine fuzzy partition, and number of antecedent rule [28] are also major focus area for consideration during trade off.

In similar way there are so many classifications like three objectives based approach, Ensemble Classifiers, User preference, High dimensional problems, semantic coin tension and context adaptation having different focus areas of attributes for handling of I-A tradeoff in EMO algorithms.

4. Multi Objective Evolutionary Algorithm In Fuzzy Classifiers

To deal with the problems related to multi objective optimization evolutionary algorithms are highly capable, because evolutionary algorithms consists an approach based on population to get multiple solutions in single run. These algorithms are also capable to deal with huge uncertain and complex search space.

During design of fuzzy systems, handling of I-A tradeoff is identified as a multi objective optimization problem. Evolutionary multi objective optimization includes integration of any of the approach like genetic algorithm [29], evolution strategies [30], genetic programming [31] and evolutionary programming [32] to deal with multi objective problems.

There are two generations of MOEA, the first generation having features, fitness sharing and niching incorporated with the rank of Pareto. Non-dominated Sorting Genetic Algorithm (NSGA) [33], Niched Pareto Genetic Algorithm (NPGA) [34], and Multi-Objective Genetic Algorithm (MOGA) [35] are first generation MOEAs.

Second generation MOEA are incorporated with the idea of elitism. The method of generating a new population practically is to enable the best rule from existing generation to carry forward to the next without any alteration. This approach is called as elitist selection and guarantees that the quality of the output obtained by genetic algorithm will not be decremented in the next generation.

Few MOEAs of Second generation are Strength Pareto Evolutionary Algorithm (SPEA) [36], Strength Pareto Evolutionary Algorithm 2 (SPEA2) [37], Pareto Achieved Evolution Strategies (PAES) [38], Non-dominated Sorting Genetic Algorithm-II (NSGA-II) [39], Niched Pareto Genetic Algorithm-II (NPGA-II) [40], Pareto Envelop based Selection Algorithm (PESA) [41], Micro Genetic Algorithm [42, 43].

5. Methodologies Related To Design Attributes Of A Fuzzy System

During design of fuzzy systems, generation and selection of rule are major factor to deal with I-A tradeoff. In a high dimensional fuzzy system, as and when inputs are joined, the rule numbers in rule base increase invariably, which result in increase of complexity and decrease of interpretability.

Fuzzy rule selection process using multi-objective genetic local search is defined in [44]. In this paper, two evaluation measures namely support and confidence have been discussed. These two measures are generally used in the area of data mining.

A method using numerical data for improving the fuzzy system design involving self generation and simplification process has been discussed in [45]. On the basis of fuzzy rules, difficulties with quantification of interpretability have been discussed in [46].

The many objectives (namely reliability, compactness, accuracy and transparency) optimization methodology is proposed in [47] for linguistic fuzzy modeling based on heuristic fully automated identification algorithms.

Many other methodologies for improving Interpretability-Accuracy simultaneously are discussed in [48, 49], which are mainly related to design attributes like rules and rule bases.

Type-2 fuzzy systems are much more capable to deal with fuzzy systems of type-1 because the fuzzy sets of type-2 have one extra dimension to deal with uncertainty. Interval fuzzy sets of type-2 are used to develop fuzzy knowledge base systems in [51], which are simpler than fuzzy systems of type-2. The implementation has been done using genetic algorithms. The interpretable fuzzy systems with improved accuracy are reviewed in [53].

6. Conclusion and Future Scope

In the design of fuzzy systems, output may be obtained by applying various rules into input variables, but there is huge number of permutations and combinations for the selection of the rule to find out the desired outcome. I-A tradeoff is identified as major issue in any fuzzy systems design.

A review and survey of I-A tradeoff, including multi-objective optimization, evolutionary algorithms, rule generation and selection, association degree, membership functions, fuzzy partitions etc is done in this paper.

In future, discovery and invention of new approaches for better I-A tradeoff, resulting improvement in the fuzzy systems design specifically for problems pertaining to classification i.e. fuzzy classifiers.

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