



A Review on the Development of Fuzzy Classifiers with Improved Interpretability and Accuracy Parameters

Farheen Azad¹ & Praveen Kr Shukla²

^{1,2}Artificial Intelligence Research Center, Department of Computer Science & Engineering, School of Engineering, Babu Banarasi Das University, Lucknow, India,

¹farheenazad9@gmail.com, ²drpraveenkumarshukla@gmail.com

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Abstract

This review paper of fuzzy classifiers with improved interpretability and accuracy parameter discussed the most fundamental aspect of very effective and powerful tools in form of probabilistic reasoning. The fuzzy logic concept allows the effective realization of approximate, vague, uncertain, dynamic, and more realistic conditions, which is closer to the actual physical world and human thinking. The fuzzy theory has the competency to catch the lack of preciseness of linguistic terms in a speech of natural language. The fuzzy theory provides a more significant competency to model humans like common-sense reasoning and conclusion making to fuzzy set and rules as good membership function. Also, in this paper reviews discussed the evaluation of the fuzzy set, type-1, type-2, and interval type-2 fuzzy system from traditional Boolean crisp set logic along with interpretability and accuracy issues in the fuzzy system.

Keywords

Fuzzy logic, Fuzzy set, Crisp sets, Accuracy and Interpretability trade off, Type-2 fuzzy system, Interval type-2 fuzzy system

1. Introduction (Heading 1)

Making a machine or system with human intelligence that can have decision-making capabilities to justify and take actions that have the good possibility of achieving a specific goal and simulation of human intelligence in machines is quite complex. The crucial problem throughout the development of knowledge-based systems is the representation and manipulation of human knowledge due to its subjective nature [1][2][4]. The System that executes primary functions or recognizes texts through optical character recognition is no longer well-advised to represent artificial intelligence since this function is now conventional as a



deep-rooted computer function. Previously Bivalent logic was used to represent the knowledge in artificial intelligence applications that has only two states, True (T) and False (F). But this logic is not sufficient to represent the imprecision, uncertainty, and subjectivity of human knowledge. To overcome with the above problem, fuzzy logic is used to represent human knowledge having a strong mathematical framework [2][3].

Traditional logic also called Crisp logic mainly uses three operations “AND, OR and NOT” and after functional completion that returns only 0 and 1. Similarly, Crisp set theory assigns objects to set as membership or non-membership in a class or group. That’s why it has strict mathematical boundaries. So that it is not to be intelligent as a machine that can behave similarly to human behavior. For example, if set to a function that has provision to consider that above the 90 degree Fahrenheit is hot the in crisp functional set return 89 is warm and 91 is hot. But in fuzzy logic same the three operations “AND, OR and NOT” return a degree of membership that is a number of the result between 0 and 1 [3][4]. This traditional approach is incapable to deal with this problem which was previously used in developing traditional artificial intelligence applications.

To prevail over the above problem, fuzzy logic is used to characterize human knowledge having a strong approach based on linguistics, computer science, mathematics, psychology, and more [5][7][16]. Interpretability and accuracy are the performance parameters of FRBS (Fuzzy Knowledge-Based Systems). They clearly expressed interpretability as the property of fuzzy systems that quantifies the comprehensibility of the system functioning by their users [16][17]. This is an overall subjective feature and its assessment is very complicated. Accuracy is another feature that shows the adjacency between the actual and modeled system. Its assessment is easy and mathematically well formulated which shows the performance of the system. The primary objective of this review is with some of the trendy proposals to attempt to address a good level between accuracy and interpretability. The fuzzy Model community looks to increase and maintain a good balance between interpretability and accuracy fuzzy models [18].

The review is enrolling as follows in section 2 define accuracy and interpretability. A fuzzy model analyzes the improvement of interpretability and accuracy and trying to find a good trade-off between them. In section 3, defines and introduces the type of fuzzy logic-based system. In section 4 points out the Outcomes of the Review and Research directions. And section 5 points out the same conclusions [18][21].

2. Interpretability and accuracy of fuzzy systems

2.1. Interpretability

Interpretability talks about the proficiency of the fuzzy model to explain the behavior of the system understandably. Interpretability is the non-objective property depending on the following properties:

- i. Model Structure
- ii. Number of input variables
- iii. Number of fuzzy rules
- iv. Number of linguistic terms
- v. Shapes of fuzzy sets

Several criteria are

- i. Compactness,
- ii. Completeness
- iii. Consistency
- iv. Transparency



2.2. Accuracy

Accuracy talks about the proficiency of the fuzzy model to faithfully represent the modeled systems. The nearer the model to the system, the higher is its accuracy points. By closeness, we understand the sameness between the responses of the real system and the fuzzy model. To obtain a high degree of accuracy and interpretability is a contradictory thing. Fuzzy Modeling is divided into two sub-areas [14][19].

When building a predictive model, focus on two main criteria i.e. predictive accuracy and interpretability, and between them generally find a trade-off relationship. There are 4 cases in the situation for Good Trade Off [14][16].

CASE 1: Magnificent Interpretability and Acceptable Accuracy

CASE 2: Great Interpretability and Great Accuracy

CASE 3: Acceptable Interpretability and Very Great Accuracy

CASE 4: Bad Interpretability and Excellent Accuracy

In general, when building a predictive model using techniques of fuzzy modeling that are oriented to obtaining rule-based systems, there are two important criteria: predictive accuracy and interpretability were with high accuracy but rarely interpretable in concurrence with the fuzzy logic principles. Both concepts conflict and it is essential to achieve a good trade-off between the two factors. Interpretability and accuracy are the performance parameters of FRBS. They defined interpretability as the property of fuzzy systems that quantifies the intelligibility of the system functioning by its users [18]. This is an overall subjective feature and its assessment is very complicated. Accuracy is another feature that shows the closeness between the real and modeled system. Its assessment is easy and mathematically well formulated which shows the performance of the system.

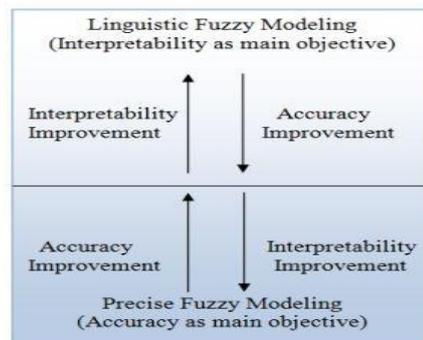


Fig.1 Improvements in Interpretability-Accuracy Trade-offs in Fuzzy Modeling [14]

3. Fuzzy systems and related system development

3.1. Fuzzy Logic

Fuzzy logic is the multi-valued logic that is first introduced in 1965 by Lotfi Zadeh. This logic provides a practical means to represent the approximate and vague knowledge. The knowledge-based systems developed using fuzzy logic is called Fuzzy Knowledge-Based Systems (FKBS). [4] Further improvements with FKBS have been carrying out in the theoretical framework of fuzzy logic. To make it more proficient to deals with unclearness. Improve systems are known as type-2 fuzzy logic. [17] Type-2 fuzzy logic ware used to develop a knowledge-based model. But the problem with type-2 fuzzy logic is its computational cost is very expensive, resulting in the loss of system performance and interpretability. [16] Mendel has proposed an improved version of type-2 fuzzy logic named 'interval type-2 fuzzy logic'. To remove the drawback of type-2 fuzzy knowledge-based, Interval type-2 fuzzy knowledge-based logic, the membership degree is represented by an interval

as an alternative of a fuzzy set. [19] Interval type-2 fuzzy knowledge-based reduces the computational expensiveness. In this research work, interval type-2 fuzzy logic has been using for modeling knowledge-based systems.

3.1.1. Type-1 fuzzy logic systems

Type-1 fuzzy logic system or Fuzzy set membership function has certain values that lie between 0 and 1. That means in type-1 fuzzy set experts can determine the degree of achieving the characteristics of the given object. In type-1 fuzzy set consequents of rules can be uncertain, a group of experts may not agree with the consequents. Measurements that activate a type-1 Fuzzy logic system may be noisy and therefore uncertain. Type-1 fuzzy sets are not able to directly model such uncertainties because their membership functions are crisp. If experts have 3 different red balls. The first is red by 65%, the second is red 74%, and the third is red 90%.

There are three kinds of Fuzzy Knowledge-Based Systems (FKBS)

- a. Linguistic or Mamdani Fuzzy Knowledge-Based System (FKBS).
- b. Takagi-Sugeno (TS) Fuzzy Knowledge-Based Systems (FKBS).
- c. Approximate or scatter partition Fuzzy Knowledge-Based Systems (FKBS)

3.1.2. Equations

In Type -2 Fuzzy set, the Expert can't determine exactly the degree of achieving the characteristics. For example, if an expert has 3 different red balls. The first is red by 75%-80%, the second is red 85%-90%, and the third is red 95%-100%. So it presents an interval fuzzy set. Type-2 fuzzy sets are the sets and systems that can handle more uncertainty. There was some criticism made at the beginning of fuzzy sets, about the fact that the type-1 fuzzy set has no uncertainty associated with membership function, and this contradicts the definition of word fuzzy and is their uncertainty about the value of the membership function

Prof. L. A. Zadeh inventor of fuzzy sets didn't stop with type-2 fuzzy sets; he also generalized all of this to type-n fuzzy sets. The present article focuses on the next step fuzzy sets in the logical progression i.e. on type-2 fuzzy sets he also introduced more fuzzy sets in the logical progression from type-1 to type-n fuzzy sets, where $n = 1, 2$.

3.1.2. Interval Type-2 Fuzzy Systems

The acceptance of Type-2 fuzzy sets is very broad in Rule-Based Fuzzy Systems (RBFs) because they handled uncertainties modeled by them while such uncertainties cannot be handled by type-1 fuzzy sets. This type of Fuzzy System is used in fuzzy logic control, fuzzy logic signal processing, and rule-based classification, etc.

3.2. Related work

In this section, we review the work concerned with fuzzy systems which have been explained into three steps.

1. Theories and discussion about accuracy & interpretability, fuzzy set, type -1, type-2 fuzzy system and interval type-2 fuzzy system.
2. Reviews the new systems developed using interval type-2 fuzzy sets and logic.
3. The interpretability and accuracy issues about fuzzy systems

In 1965, Prof. L. A. Zadeh, generally known as the father of fuzzy logic introduced a new mathematical mechanism to represent human knowledge, coined the name of fuzzy logic. Fuzzy logic is the multi-valued logic. This logic provides a practical means to represent the approximate and vague knowledge. The knowledge-based systems developed using fuzzy logic are called Fuzzy Knowledge-Based Systems (FRBS).[1]

In the early 1990s, the work in the area of EMOFS was oriented towards the development of accurate fuzzy systems, with less concentration on interpretability. However, in the late 1990s, interpretability became an important issue along with accuracy. Table 1 summarizes most of the work on the issues discussed above in the decade after 2010.



Table 1. Fuzzy logic related work after 2010.

Approaches developed	Focus	References
Conflating features of Fuzzy knowledge-based system during its design and development.	Accuracy and Interpretability trade-off	[1][2][3][4]
Use of multi-dimensional fuzzy membership function.	Accuracy and Scalability Improvement	[5][6][7]
Scalability and hierarchical fuzzy system	Accuracy and Scalability Improvement	[8][9][11]
A qualified study of type-2 fuzzy logic systems.	Efficiency and performance of fuzzy system.	[3][12][13][14][15][16][17][18]
Use of GA to tune the interval type-2 fuzzy knowledge-based systems.	Control based efficiency and performance of fuzzy system.	[5][14][15][19][20][21][22][28][29]

Further improvements have been carried out in the theoretical framework of the fuzzy logic making it more capable to deal with uncertainty and are known as ‘type-2 fuzzy logic’. The type-2 fuzzy logic has also been used to develop knowledge-based systems, but this logic is computationally very expensive resulting in the loss of system performance and interpretability.

To remove this drawback, Liang and Mendel introduced the concepts of upper and lower bound for the interval type-2 fuzzy system are in along with an effective method of inference mechanism for Gaussian fuzzy membership functions. Their membership degree is represented by an interval in place of a fuzzy set. [65]

The fundamental development and theoretical progress in interval type-2 fuzzy systems and type-2 fuzzy systems are discussed by Mendel [66]. In the interval type-2 fuzzy sets, the computation of centroids is an important operation that is a very time-consuming task. To deal with this problem, KM iterative algorithm is used to execute this operation in Mendel. Further, it has been proved that this algorithm converges monotonically and fast super-exponentially [66]. A new mechanism for centroids type-reduction strategy is introduced [66], especially for type-2 fuzzy sets. This mechanism uses a α -plane representation and centroids type reduction is performed on each α -plane. The computational complexity is improved from exponential to linear using this approach.

3.3. Type- 2 Fuzzy logic based system overview and their applications

A summary discussion about the most contemporary and successful research applications of type-2 fuzzy logic is provided in this section. The design of type-2 fuzzy logic systems has been mainly focused on handling the uncertainty in the information in an attempt to improve the performance of the system for the particular application it was built for. It has been shown that a type-2 fuzzy logic outperforms a type-1 in various ways; however, the construction of the type-2 fuzzy rules is the same as for the type-1 cases. [67].

In 2010, Hosseini et al. recommended a genetic type-2 fuzzy logic system for pattern recognition in CAD systems. Their approach was accommodating in tuning and generating T2 Gaussian membership function (Type -2 GMF). Type -2 GMF parameters showing how the intervals type-2 fuzzy logic system (IT2FLS) methodologies based on the Mamdani rules model handles problems in pattern recognition [13].

A new model was given by Chin Wang Lou, Ming Chui Dong in 2012. In their approach [36] they used type-2 Fuzzy sets to form a fuzzy neural network, which was self-adapting and self-developing in nature. The model proved to be accurate and

significant in comparison to other methods proposed in existing works for load forecasting. In 2010, Melin proposed the application of interval type-2 FL for pattern recognition and processing of images [13][18].

In 2012, a new model was given by Chin Wang Lou, Ming Chui Dong.[36] In their approach, they used type-2 Fuzzy sets to form a fuzzy neural network (FNN), which was self-adapting and self-developing in nature. The model proved to be accurate and significant in comparison to other methods proposed in existing works for load forecasting. Melin proposed the application of interval type-2 FL for the processing of images and pattern recognition [18].

3.4. Interpretability issues and interpretability-accuracy trade-off

“Unfortunately, the predictive models that are most powerful are usually the least interpretable” [61].

When building a predictive model, focus on two important criteria, that is predictive accuracy and Interpretability, and between them generally find a trade-off relationship Interpretability. [36] And accuracy are two promising features of any fuzzy system. Interpretability demonstrates the proficiency of a human being to understand the functioning of any fuzzy system by inspecting its rule base and database [20]. Shukla and Tripathi discussed the interpretability and accuracy contradicting each other, i.e., the increment in one feature leads to the deterioration in another feature. This situation is also called interpretability accuracy trade-off [16].

Fuzzy systems are extremely applicable in many applications in the context of smart cities. The interaction between intelligent systems and people results into the development of cognitive cities. In the case of cognitive cities, the interpretable fuzzy systems are extremely utilized [12]. The review on interpretability and accuracy trade-off is carried out by Shukla and Tripathi [14][15]. They discussed interpretability issues in evolutionary multi-objective fuzzy systems and the uncertainty handling issue in FRBS.

In evolutionary fuzzy systems, the interpretability accuracy trade-off is well discussed in the case of software deliverables by Shukla and Tripathi [19]. In Chandra et al., one FRBS named MOBI-CLASS is designed and implemented using Guaje Open Access Software [9][14][19]. A modified deep rule-based fuzzy model (DRBFS) has been developed in Davoodi and Moradi, which consists of the integration of static and temporal information of variables. The proposed system interpretability is preserved by using a stacked structure in DRBFS [40].

4. Outcomes of the Review and Research directions

The fuzzy Logic approach withdraws from the rigid limitations of Boolean Logic and allows extraordinary flexibility. Fuzzy logic and Fuzzy sets are very strong tools for managing complexities. Their use encourages to built relation between mathematical models and the associated physical reality. Interval type-2 fuzzy systems have shown the benefits of type-2 fuzzy, basically extended from the concepts of traditional type-1 systems with reduced computational cost and complexity. These systems are extremely applicable in control systems, optimization problems, machine learning, and other hybrid computational intelligence techniques. Interval type-2 fuzzy system reduced the cost of computation as compared to the fuzzy type-2 fuzzy system. For the Control system, optimization system, machine learning, and other hybrid computational intelligence technique there is Interval fuzzy system is extremely well suited.

Following are the challenging research issues in type-2 fuzzy systems.

- a. Improving the computational performance
- b. Improvement in the understanding and representation of uncertainty.
- c. Development of more effective type reducing techniques
- d. Quantification and formulation of interpretability and identification of its global Definition.
- e. Invention of new opportunities for the integration of evolutionary approaches.
- f. Integration of scaling parameters, i.e., linguistic hedges and linguistic modifiers.



- g. Development of techniques for interpretable explanations for fuzzy reasoning, inference mechanism and quantification of explanation ability.

The chart given in Figure-2 is showing the publications statistics. In this work, publications of three domains are studied and analyzed, i.e., type-1 fuzzy systems, interval type-2 fuzzy systems, and evolutionary interval type-2 fuzzy systems.

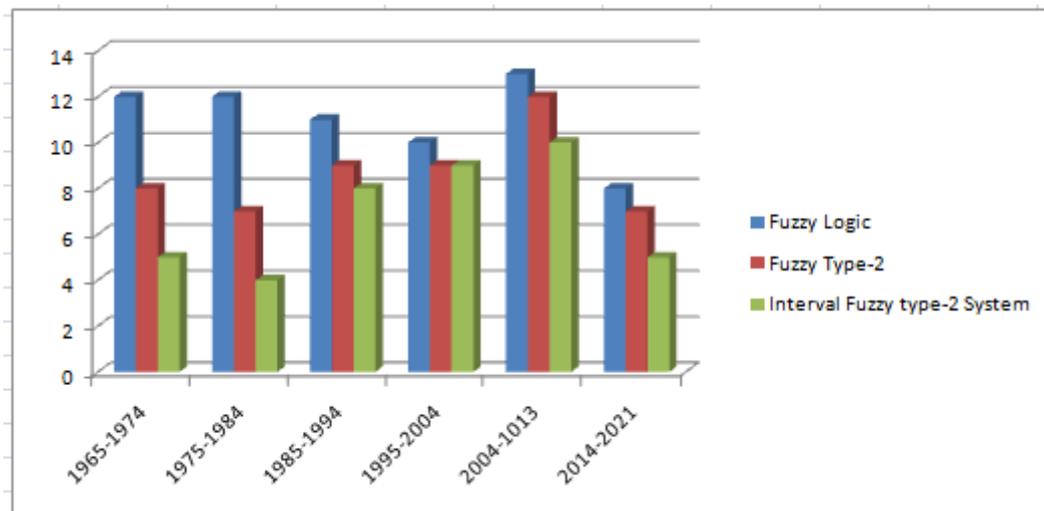


Figure 1. Publications statistics of different domains

5. Conclusion and future scope

It is concluded after the review that type-2 fuzzy systems are more realistic than the simple type-1 fuzzy systems, but the interpretability of the system is compromised. To establish more accurate systems with better Interpretability fuzzy systems, interval type-2 fuzzy systems are found suitable which provide a well-defined mechanism to represent the degree of uncertainty with low time complexity. But still there is a big scope to improve and define uncertainty. Also, Interpretability- accuracy tradeoff is another important research dimension in all types of fuzzy systems their problem needs to be addressed. In the future, authors are interested to develop a new mechanism for improvement in the representation of vagueness and uncertainty with interpretability quantification and handling interpretability-accuracy trade-off.

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