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Fuzzy sets in pattern recognition and machine intelligence

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Abstract

Fuzzy sets constitute the oldest and most reported soft computing paradigm. They are well-suited to modeling different forms of uncertainties and ambiguities, often encountered in real life. Integration of fuzzy sets with other soft computing tools has lead to the generation of more powerful, intelligent and efficient systems. In this position paper we seek to outline the contribution of fuzzy sets to pattern recognition, image processing, and machine intelligence over the last 40 years.

Keywords: Fuzzy logic; Neuro-fuzzy computing; Data mining; Image processing; Pattern recognition; Bioinformatics

1. Introduction

Fuzzy sets were introduced in 1965 by Zadeh [20] as a new way of representing vagueness in everyday life. This theory provides an approximate and yet effective means for describing the characteristics of a system that is too complex or ill-defined to admit precise mathematical analysis. Fuzzy approach is based on the premise that key elements in human thinking are not just numbers but can be approximated to tables of fuzzy sets, or, in other words, classes of objects in which the transition from membership to nonmembership is gradual rather than abrupt. Much of the logic behind human reasoning is not the traditional two-valued or even multivalued logic, but logic with fuzzy truths, fuzzy connectives, and fuzzy rules of inference. This fuzzy logic plays a basic role in various aspects of the human thought process. Fuzzy set theory is the oldest and most widely reported component of present-day *soft computing* (or computational intelligence), which deals with the design of flexible information processing systems.

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These provide soft decision by taking into account characteristics like tractability, robustness, low cost, etc., and have close resemblance to human decision making.

The significance of fuzzy set theory in the realm of pattern recognition [1–5,10,11,17–19,23]. is adequately justified in

- Representing linguistically phrased input features for processing.
- Providing an estimate (representation) of missing information in terms of membership values.
- Representing multiclass membership of ambiguous patterns and in generating rules and inferences in linguistic form.
- Extracting ill-defined image regions, primitives, and properties and describing relations among them as fuzzy subsets.

It is seen that the concept of fuzzy sets can be used at the *feature level* in representing input data as an array of membership values denoting the degree of possession of certain properties; in representing linguistically phrased input features for their processing; in weakening the strong commitments for extracting ill-defined image regions, properties, primitives, and relations among them; and at the *classification level*, for representing class membership of objects, and for providing an estimate (or representation) of missing information in terms of membership values. In other words, fuzzy set theory provides a notion of embedding; we find a better solution to a crisp problem by looking in a large space at first, which has different (usually less) constraints and therefore allows the algorithm more freedom to avoid errors forced by commission to hard answers in intermediate stages.

The use of linguistic features may be viewed as a form of data compression, that can be termed granulation. Information granules are collections of entities drawn together by their similarity, functional, spatial or temporal proximity. A similar effect can also be achieved by conventional quantization. However, in the case of quantization the values are intervals, whereas in the case of granulation the values are overlapping fuzzy sets. The advantages of granulation over quantization are that:

- It is more general.
- It mimics the way in which humans interpret linguistic values.
- The transition from one linguistic value to a contiguous linguistic value is gradual rather than abrupt, resulting in continuity and robustness.

In this position paper we mention the role of fuzzy sets in traditional pattern recognition and image processing, followed by its hybridization with other soft computing tools. We conclude by highlighting its recent developments in mining large datasets, along with possible future applications. Some of the research centers over the world are also listed.

2. Pattern recognition and image processing

Research on the application of fuzzy set theory to *supervised* pattern recognition was started in 1966 in the seminal note of Bellman et al. [1] where the two basic operations—abstraction and generalization—were proposed. Abstraction in fuzzy set theory means estimation of a membership function of a fuzzy class from the training samples. Having obtained the estimate, generalization is performed when this estimate is used to compute the values of the membership for unknown objects not contained in the training set. Consideration of linguistic features and fuzzy relations in representing a class has also been suggested by Zadeh. Subsequently, multivalued recognition system and fuzzy k-NN rule, among others, have been developed in the supervised framework.

Fuzzy set theory has been extensively used in clustering problems where the task is to provide class labels to input data (partitioning of feature space) under *unsupervised* mode based on certain criterion. A seminal contribution to cluster analysis was Ruspini's concept [19] of a fuzzy partition. This was followed by the design of fuzzy c-means, fuzzy ISODATA, fuzzy DYNOC [2,3] and other possibilistic clustering algorithms. Although the task of feature selection plays an important role in designing a pattern recognition system, the research in this area using fuzzy set theory has not been significant, as compared to classification or clustering. Applications of fuzzy pattern recognition and image processing have been reported in various domains [3,11], like speech recognition, remotely sensed images, medical imagery, and atmospheric sciences.

A gray tone image possesses some ambiguity within the pixels due to the possible multivalued levels of brightness. This pattern indeterminacy is due to inherent vagueness rather than randomness. The incertitude in an image pattern may be explained in terms of grayness ambiguity or spatial (geometrical) ambiguity or both. Grayness ambiguity means *indefiniteness* in deciding a pixel as white or black. Spatial ambiguity refers to indefiniteness in shape and geometry (e.g., in defining centroid, sharp edge, perfect focusing). These aspects are handled under the area fuzzy image processing, that grew up almost in parallel with fuzzy pattern recognition. It is based on the very concept that the basic definitions of edge, boundary, region, and the relations between them, do not lend themselves to precise formulation. In fact, in 1970, Prewitt [17] first mentioned that gray image segments should be fuzzy subsets of an image.

A recognition system should have sufficient provision for representing the uncertainties involved at every stage, i.e., in defining image regions, its features and relations among them, and in their matching, so that it retains as much as possible the information content of the original input image for making a decision at the highest level. It, therefore, becomes natural, convenient and appropriate to avoid committing ourselves to a specific hard decision by allowing the segments or skeletons or contours to be fuzzy subsets of the image; the subsets being characterized by the possibility of a pixel belonging to them. Fuzzy measures and methodologies, like fuzzy entropy, fuzzy geometry, fuzzy medial axis transform, fuzzy Hough transform, and other fuzzy processing algorithms, have been developed to manage the uncertainty.

3. Integration in soft computing

Several attempts were made during the 1990s to evolve different hybrid approaches to pattern recognition by combining the merits of individual techniques. A judicious integration of neural network and fuzzy theory, commonly known as *neuro-fuzzy computing*, is one such hybrid paradigm which is most visible and has been adequately investigated. This allows one to incorporate the generic advantages of artificial neural networks and fuzzy logic-like massive parallelism, robustness, learning, and handling of uncertainty and impreciseness, into the system. Moreover, some application specific merits can also be incorporated. For example, in the case of pattern classification and rule generation, one can exploit the capability of neural nets in generating highly nonlinear decision boundaries, and model the uncertainties in the input description and output decision by the concept of fuzzy sets. Often the neuro-fuzzy model is found to perform better than either a neural network or a fuzzy system considered individually. In effect there is a symbiotic combination of different soft computing tools for flexible information processing, in order to deal with real life ambiguous situations and to achieve tractability, robustness, and low-cost solutions [21,22].

Neuro-fuzzy hybridization is done broadly in two ways: a neural network equipped with the capability of handling fuzzy information [termed *fuzzy-neural* network (FNN)], and a fuzzy system augmented by neural networks to enhance some of its characteristics like flexibility, speed, and adaptability [termed *neural-fuzzy* system (NFS)] [12]. In an FNN either the input signals and/or connection weights and/or the outputs are fuzzy subsets or membership values to some fuzzy sets [14]. Usually linguistic values such as *low*, *medium*, and *high*, or fuzzy numbers or intervals are used to model these. Neural networks with fuzzy neurons are also termed FNN as they are capable of processing fuzzy information. A NFS, on the other hand, is designed to realize the process of fuzzy reasoning, where the connection weights of the network correspond to the parameters of fuzzy reasoning. The NFS architecture has distinct nodes for antecedent clauses, conjunction operators, and consequent clauses.

Subsequently, hybridization of fuzzy sets has been investigated using other soft computing tools like genetic algorithms and rough sets [14]. Here the searching potential of genetic algorithms and the capacity of rough sets in handling uncertainties arising from granulation in information systems are utilized in designing more efficient, intelligent systems.

4. Application to data mining and granular computing

There is a growing indisputable role of fuzzy sets in the realm of data mining and knowledge discovery in databases. Knowledge discovery in databases is mainly concerned with identifying interesting patterns and describing them in a concise and meaningful manner. Despite a growing versatility of knowledge discovery systems, there is an important component of human interaction that is inherent to any process of knowledge representation, manipulation, and processing. Fuzzy sets are naturally inclined towards coping with linguistic domain knowledge and producing more interpretable solutions. These concepts have been successfully employed in fuzzy association rule mining and data summarization. The notion of *interestingness*, which encompasses several features such as validity, novelty, usefulness, and simplicity, can be quantified through fuzzy sets.

Data mining [6,8,13] aims at sifting through large volumes of data in order to reveal useful information in the form of new relationships, patterns, or clusters, for decision-making by a user. Fuzzy sets support a focused search, specified in linguistic terms, through data. This helps prevent searching for meaningless or trivial patterns in a database. Fuzzy sets also help discover dependencies (or relationships) between data in qualitative or semiqualitative format.

Fuzzy neural networks are employed to learn and extract rules in natural form. These rules can help mine a meaningful and user-friendly interpretation of dependencies between attributes, from amongst a large volume of data. Researchers have developed fuzzy clustering algorithms, which try to achieve attribute focus by first recognizing the most interesting features. The objective is to generate cohesive and comprehensible information *nuggets* by sifting out uninteresting attributes. Often noncrisp values are handled by granularization followed by partitioning.

Granular computing [13,15] concerns with computation using granules, i.e., a chunk of points which cannot be discriminated in terms of the given attributes or relations. Since granules involve compressed information, granular computing provides gain in computation time; and is thereby suitable for handling large datasets. Granules are regarded as essential entities in all cognitive pursuits geared toward establishing meaningful patterns in data. There can also be fuzzy granules, defined in terms of membership functions.

The concept of granular computing also enables one to split an overall computing effort into several subtasks, leading to a modularization effect. This allows speeding up convergence while employing a divide-and-conquer strategy to mine a large dataset. Other significant recent applications of fuzzy sets, that have shown strong promise, include bioinformatics and web mining [7,9,16]. Some examples involve the use of fuzzy similarity between strings and determination of fuzzy relevance for page ranking.

5. Dedicated research centers

The success of fuzzy sets has been mainly vindicated by the commercial popularity in Japan of fuzzy logic and control systems, where both pattern recognition and image processing provide direct interaction and support. Some international centers of repute, devoted to research in soft computing, are Fuzzy Logic Systems Institute (FLSI), the RIKEN Brain Science Institute, Japan, and BISC, University of California at Berkeley, USA. Recently a national facility, dedicated to both basic and applied soft computing research, has been set up at the Indian Statistical Institute, Kolkata under the patronage of the Department of Science and Technology, Government of India, because of the outstanding contribution of the members of the Machine Intelligence Unit since 1975. The Center has provision for formal collaboration with overseas universities and institutes.

References

[1] R. Bellman, R. Kalaba, L.A. Zadeh, Abstraction and pattern classification, J. Math. Anal. Appl. 13 (1966) 1–7.
[2] J.C. Bezdek, Pattern Recognition with Fuzzy Objective Function Algorithms, Plenum Press, New York, 1981.
[3] J.C. Bezdek, S.K. Pal (Eds.), Fuzzy Models for Pattern Recognition: Methods that Search for Structures in Data, IEEE Press, New York, 1992.
[4] A. Ghosh, S.K. Pal (Eds.), Soft Computing Approach to Pattern Recognition and Image Processing, World Scientific, Singapore, 2003.
[5] A. Kandel, Fuzzy Mathematical Techniques with Applications, Addison-Wesley, Reading, MA, 1986.
[6] S. Mitra, T. Acharya, Data Mining: Multimedia, Soft Computing, and Bioinformatics, Wiley, New York, 2003.
[7] S. Mitra, H.L. Larsen (Guest Eds.), Special Issue of Fuzzy Sets and Systems on Web mining using Soft computing 148(1) (2004).
[8] S. Mitra, S.K. Pal, P. Mitra, Data mining in soft computing framework: a survey, IEEE Trans. Neural Networks 13 (2002) 3–14.
[9] M. Nikravesh, V. Loia, B. Azvine, Fuzzy Logic and the Internet (FLINT), World Wide Web and Search Engines, International Journal of Soft Computing—Special Issue in FLINT, 2002.
[10] S.K. Pal, Fuzzy image processing and recognition: uncertainty handling and applications, Internat. J. Image Graphics 1 (2001) 169–195.
[11] S.K. Pal, D. Dutta Majumder, Fuzzy Mathematical Approach to Pattern Recognition, Wiley, Halsted Press, New York, 1986.
[12] S.K. Pal, S. Mitra, Neuro-Fuzzy Pattern Recognition: Methods in Soft Computing, Wiley, New York, 1999.
[13] S.K. Pal, P. Mitra, Pattern Recognition Algorithms for Data Mining: Scalability Knowledge Discovery, and Soft Granular Computing, CRC, Washington, 2004.
[14] S.K. Pal, A. Skowron (Eds.), Rough-Fuzzy Hybridization: A New Trend in Decision Making, Springer, Heidelberg, 1999.
[15] S.K. Pal, S.C.K. Shiu, Foundations of Soft Case-Based Reasoning, Wiley, New York, 2004.
[16] S.K. Pal, V. Talwar, P. Mitra, Web mining in soft computing framework: relevance, state of the art and future directions, IEEE Trans. Neural Networks 13 (2002) 1163–1177.

[17] J.M.S. Prewitt, Object enhancement and extraction, in: B.S. Lipkin, A. Rosenfeld (Eds.), Picture Processing and Psycho-Pictorics, Academic Press, New York, 1970, pp. 75–149.
[18] A. Rosenfeld, The fuzzy geometry of image subsets, Pattern Recognition Lett. 2 (1984) 311–317.
[19] E.H. Ruspini, A new approach to classification, Inform. Control 15 (1969) 22–32.
[20] L.A. Zadeh, Fuzzy sets, Inform. Control 8 (1965) 338–353.
[21] L.A. Zadeh, Fuzzy logic, neural networks, and soft computing, Comm. ACM 37 (1994) 77–84.
[22] L.A. Zadeh, A new direction in AI: toward a computational theory of perceptions, AI Magazine 22 (2001) 73–84.
[23] L.A. Zadeh, K.S. Fu, K. Tanaka, M. Shimura, Fuzzy Sets and their Applications to Cognitive and Decision Processes, Academic Press, London, 1975.