Information Sciences 336 (2016) 75–91

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Belief rule based expert system for classification problems with new rule activation and weight calculation procedures

Leilei Chang[a], ZhiJie Zhou[a,*], Yuan You[a], Longhao Yang[b], Zhiguo Zhou[c]

[a] High-Tech Institute of Xi'an, Xi'an, Shaanxi 710025, PR China
[b] Decision Sciences Institute, Fuzhou University, Fuzhou University, Fuzhou 350116, PR China
[c] Department of Radiation Oncology, The University of Texas Southwestern Medical Center, Dallas, TX 75235, USA

ARTICLE INFO

Article history:
Received 20 June 2015
Revised 11 November 2015
Accepted 4 December 2015
Available online 21 December 2015

Keywords:
Classification problems
Belief rule base
Optimization algorithm

ABSTRACT

Classification problems are significant because they constitute a meta-model for multiple theoretical and practical applications from a wide range of fields. The belief rule based (BRB) expert system has shown potentials in dealing with both quantitative and qualitative information under uncertainty. In this study, a BRB classifier is proposed to solve the classification problem. However, two challenges must be addressed. First, the size of the BRB classifier must be controlled within a feasible range for better expert involvement. Second, the initial parameters of the BRB classifier must be optimized by learning from the experts' knowledge and/or historic data. Therefore, new rule activation and weight calculation procedures are proposed to downsize the BRB classifier while maintaining the matching degree calculation procedure. Moreover, the optimal algorithm using the evidential reasoning (ER) algorithm as the inference engine and the differential evolution (DE) algorithm as the optimization engine is proposed to identify the fittest parameters, including the referenced values of the antecedent attributes, the weights of the rules and the beliefs of the degrees in the conclusion. Five benchmarks, namely, iris, wine, glass, cancer and pima, are studied to validate the efficiency of the proposed BRB classifier. The result shows that all five benchmarks could be precisely modeled with a limited number of rules. The proposed BRB classifier has also shown superior performance in comparing it with the results in the literature.

1. Introduction

Classification problems are fundamental to solving many theoretical and practical applications, including pattern recognition [20], medical diagnosis [15], and image processing [19]. However, classification problems are complex due to the interconnected sophistications of the correlations among the high dimensions [28]. Therefore, solving classification problems is one of the most pressing challenges in these fields.

Many attempts have been made to solve the classification problem. The prevailing approaches to solving this problem include k nearest neighbors (kNN) [2], support vector machine (SVM) [22], evolutionary algorithm-based approaches [23], and the decision tree [9]. Moreover, some more interesting and non-conventional techniques were introduced, including the

* Corresponding author. Tel.: +86 29 84744954.
E-mail address: zhouzj04@mails.tsinghua.edu.cn (Z. Zhou).

http://dx.doi.org/10.1016/j.ins.2015.12.009
0020-0255/

Learning Automata (LA)-based classifier [3], gravitational inspired classifier [27], feature vector graph-based classifier [44], and the blood pressure regularization-based classifier [25].

However, three challenges must be further addressed to better understand and solve the problem. First, human knowledge must be included in the classifiers. Human knowledge plays a key role in understanding the complex correlations among high dimensions residing in classification problems. However, its vagueness and uncertainty renders human knowledge difficult to fit into any conventional classifier [13]. Second, noise data would interfere and even diminish the applicability of the classifiers. The data are the representation of the classification problems, and it always involves certain noise in either benchmarks or practical cases. Even a small fraction of noise data could cause great interference and degrade the efficiency of the classifiers [14]. The impact of noise must be reduced. Finally, the Bayesian inference approach could not be directly applied because a good knowledge of the actual probability distribution for the characteristic variables is lacking [34].

Some researchers have used expert systems to model the human inference process. Thus far, several expert-systems-based techniques have been introduced to identify the hidden structural information and interconnected correlations of the classification problem. Of these, the artificial neural network (ANN) and the fuzzy set, as well as their combinations with other techniques, have been applied in many attempts and produced promising results [13].

ANN is comprised of multiple neural units and can precisely record a system's behavior while requiring no extra information other than the initial data [24]. Moreover, multiple ANNs could be layered to integrate and reinforce the prediction results of a single ANN when the classification problems are of over-numbered attributes [1]. However, ANN is essentially a black box [14], which makes the training and learning process unreachable and further denies access to experts' knowledge and experience.

The fuzzy set was first proposed by Zadeh in 1965 [40] and uses the "IF-THEN" rule as a semantic means to represent ambiguous human knowledge [18] in various forms, including numbers, intervals, fuzzy numbers and random numbers [43]. Fuzzy set-related and -based approaches have been applied to solving the classification problem and obtained relatively satisfactory results [14,15,18,20]. However, it has been argued that fuzzy set was heavily dependent on the choice of parameters, particularly the number of fuzzy partitions and the number of rules [13].

With this, it is natural for some scholars to combine ANN with the fuzzy set and apply it to the classification problem [21,49]. Moreover, other techniques have been combined with ANN and the fuzzy set to generate new classifiers with new features [23,27].

The Belief Rule Based (BRB) expert system extends "IF-THEN" rules (which are also used in fuzzy set) from mere linguistic terms to include numerical inputs [39]. Therefore, BRB can absorb both qualitative/linguistic and quantitative/numerical information under uncertainty as well as incompleteness [38]. This extension makes BRB versatile to more applicable fields. The result of BRB is also in the same belief structure as the input, which preserves the consistency of the deduction process. Moreover, BRB is a "white box" that makes the training and learning process available for experts' involvement. Thus far, BRB has been successfully applied in various fields, including system behavior prediction [45], system readiness assessment [4] and military capabilities assessment [16].

The information handled by BRB is also of ambiguous and uncertain characteristics and shares certain similarities with "fuzziness". However, these two approaches differ from each other. The fuzzy set uses the membership function to represent the degree of an object belonging to a certain set and therefore the information could be handled in a more comprehensive and reasonable fashion [40,43]. However, BRB uses the belief function, which contains the designated scales as well as the corresponding beliefs for integrating both subjective and objective information under uncertainty [38]. In fact, Zadeh, proposed the fuzzy set theory and made the first attempt to extend the belief rules under the fuzzy environment based on his work on the concept of information granularity and the theory of possibility [41,42]. Additional studies were later conducted to further explore both theoretical and practical aspects. Readers can refer to the literature [35,36] and references therein for more information.

To utilize the BRB system in classification problems more efficiently, two challenges must be addressed. First, the BRB systems must be downsized because a BRB classifier with too many rules is impossible to construct either by experts or by using historic data [6], which is also faced by the fuzzy set [13]. Second, initial parameters of the BRB classifier must be optimized to increase their precision in solving classification problems [45,47].

For the first challenge, new rule activation and weight calculation procedures are proposed here for the first time by assuming the attributes that are "disjunctive" (while the conventional matching degree calculation procedure remains).

For the second challenge, certain BRB parameters must be trained and optimized. There have been multiple studies regarding this topic [8,45,47]. Three dilemmas must be addressed [5]: First, numerical referenced values of the antecedent attributes must be transformed into linguistic terms. Second, the initial solution has great impact on the optimization results. Last, BRB is not necessarily downsized, which is also encountered using the fuzzy set. In this study, The Evidential Reasoning (ER) algorithm [38,45,47] is used as the inference engine to integrate the activated belief rules, and the Differential Evolutionary (DE) algorithm is adopted as the optimization engine. Existing studies have all used deterministic means as the optimization engine.

In contrast to the literature [8,45,47], the referenced values of the attributes are included as the parameters. By using this method, the numerical referenced values of the attributes do not have to be discretized into linguistic terms. Additionally, this method also helps avoid optimization performance degradation. Moreover, the inclusion of the referenced values of