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TACO-miner: An ant colony based algorithm for rule extraction from trained neural networks

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ABSTRACT

Extracting classification rules from data is an important task of data mining and gaining considerable more attention in recent years. In this paper, a new meta-heuristic algorithm which is called as TACO-miner is proposed for rule extraction from artificial neural networks (ANN). The proposed rule extraction algorithm actually works on the trained ANNs in order to discover the hidden knowledge which is available in the form of connection weights within ANN structure. The proposed algorithm is mainly based on a meta-heuristic which is known as touring ant colony optimization (TACO) and consists of two-step hierarchical structure. The proposed algorithm is experimentally evaluated on six binary and n-ary classification benchmark data sets. Results of the comparative study show that TACO-miner is able to discover accurate and concise classification rules.

1. Introduction

Data mining (DM) or in other words "the extraction of hidden predictive information from data" is a powerful new technology with great potential to help users focus on the most important information in large data sets. The general goal of DM is to discover knowledge that is not only correct, but also comprehensible and interesting for the user. Among the various data mining algorithms such as clustering, association rule finding, data generalization and summarization, classification is gaining significant attention which aims to predict the classes of future data objects.

Classification is the process of finding a set of models or functions which describe and distinguish data classes or concepts, for the purpose of being able to use the model to predict the class of objects whose class label is unknown (Han & Kamber, 2001). Classification formulates a classification model based on the analysis of a set of training data. In classification, a rule generally represents discovered knowledge in the form of **IF-THEN** rules as follows: **IF** "condition(s)" **THEN** "class". The antecedent (conditions) part of the rule contains a logical combination of predictor attributes and the consequent (class) part of the rule contains the class predicted for cases whose predictor attributes satisfy the antecedent part of the rule. Here, the main goal of rule extraction is to discover hidden knowledge and explain it understandably, to extract previously unknown relations and to ensure reasoning and defining capability (Parpinelli, Lopes, & Freitas, 2002a,chap. X).

Tan, Yu, and Ang (2006a) categorized the classification methods into two groups which are non-rule-based (ANN, support vector machines: SVM) and rule-based classification methods (C4.5, decision table, etc.). The rule-based classification methods directly extract hidden knowledge from the data and users can easily understand them. Non-rule-based classification methods are generally more accurate than rule-based classification methods but they act as a black-box and less competitive in terms of comprehensibility.

In recent years, there have been numerous attempts for applying several algorithms in data mining to accomplish classification task. Table 1 presents the recent literature on the classification methods. ANN is one of the most widely used techniques in classification. ANN is an abstract simulation of a real nervous system that contains a collection of neuron units communicating with each other via axon connections. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning process. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process.

ANN method is highly accurate in classification and prediction of output. However they have the well-known disadvantage of having black-box nature and not discovering any high-level rule that can be used as a support for human understanding (Özbakır, Baykasoğlu, & Kulluk, 2008). This is mainly because classification

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Table 1
Literature review of classification methods.

Type	Literature	Algorithm
Rule-based classification methods	Bojarczuk et al. (2004)	Constrained-syntax genetic programming
	Dehuri and Mall (2006)	Improved niched Pareto genetic algorithm (INPGA)
	Chen and Hsu (2006)	Genetic algorithm
	Tan et al. (2006a)	Dual objective evolutionary algorithm (DOEA)
	Tan et al. (2006b)	Coevolutionary algorithm (CORE)
	Hoffmann et al. (2007)	Evolutionary fuzzy rule learners
	Baykasoğlu and Özbakır (2007)	Multi-expression programming (MEPAR-miner)
	Parpinelli et al. (2002b)	Ant colony optimization algorithm (Ant-Miner)
	Holden and Freitas (2005)	Hybrid particle swarm optimization/ant colony optimization algorithm (PSO/ACO)
	Smaldon and Freitas (2006)	Ant colony optimization (unordered rule set Ant-Miner)
	Holden and Freitas (2007)	Hybrid particle swarm optimization/ant colony optimization algorithm (PSO/ACO2)
	Chen et al. (2006)	Gain based association rule classification (GARC)
	Thabtah and Cowling (2007)	Association rule mining (ranked multilabel rule – RMR)
Rule extraction from non-rule-based classification methods	Martens et al. (2007)	Support vector machines
	Santos et al. (2000)	Neural networks/genetic algorithm
	Mak and Munakata (2002)	Neural networks–rough sets–ID3
	Setiono and Thong (2004)	Neural networks
	Elalfi et al. (2004)	Neural networks/genetic algorithm
	Markowska-Kaczmar and Wnuk-Lipinski (2004)	Neural networks/genetic algorithm
	Li and Wang (2004)	Neural networks/rough set
	Markowska-Kaczmar (2005)	Neural networks/evolutionary algorithm
	Tokinaga et al. (2005)	Neural networks/genetic programming
	Hruschka and Ebecken (2006)	Neural networks/genetic algorithm
	Saad and Wunsch (2007)	Neural networks
	Setiono et al. (in press)	Neural networks
	Kahramanli and Allahverdi (2009)	Neural networks/artificial immune systems

and function approximation concepts of ANN solutions consist of a large number of interacting non-linear elements, characterized by large sets of real-valued parameters which are hard to interpret. Distributed internal representations make it even harder to understand what exactly a network has learned and where it will fail to generate correct answer (Kuttuyil, 2004). Due to this reason, many researchers tend to develop new algorithms for rule extraction from ANNs.

Algorithms for rule extraction from ANNs are grouped into three categories according to translucency dimension of classification which is designed to reveal the relationship between the extracted rules and the internal architecture of the trained ANNs. Decompositional approaches involve rule extraction at the level of hidden and output units, which are mapped in a binary form (Hruschka & Ebecken, 2006). Pedagogical approaches try to map inputs directly into outputs and views ANNs as a black-box. Finally eclectic approaches incorporate elements of both pedagogical and decompositional techniques. There are so many studies for rule extraction from artificial neural networks in the literature. Most of the algorithms are based on evolutionary algorithms for rule extraction from ANNs.

Ant colony optimization algorithm (ACO) is applied to many optimization problems successfully until now. However, we have observed that ACO is not applied to ANN rule problems except author's preliminary work (Özbakır et al., 2008). In this study a new algorithm which is named as TACO-miner is proposed and implemented for rule extraction from trained neural networks. The proposed algorithm is based on touring ant colony optimization (TACO). TACO-miner is designed as to extract rules by using the weights obtained from trained neural networks. The proposed approach is a decompositional approach which is based on the work of Elalfi, Haque, and Elalami (2004). Elalfi et al. (2004) presented an algorithm for extracting rules from databases via trained neural network using a genetic algorithm. Genetic algorithm was used to find the optimal values of the input attributes, which maximize the output function of the output nodes. They decoded the optimal chromosome and used to get a rule which belongs to a target class. Kahramanli and Allahverdi (2009) also presented a similar method that uses artificial immune systems algorithm to extract rules from trained adaptive neural networks. The aim of their study was to develop a new adaptive activation function and a new method for rule extraction from trained ANNs.

In this study, a rule representation scheme which is similar to Elalfi et al. (2004) is used. However in the present study, various activation functions are considered and experimental design is also performed in order to determine the best parameter settings for ANNs. These were not carried out in the previous studies. Moreover, a classification fitness function is also incorporated into the proposed algorithm in order to perform rule induction. Binary ant colony optimization algorithm is applied to extract classification rules from the trained neural networks.

The remainder of this paper is organized as follows: Section 2 explains the ant colony and touring ant colony optimization algorithms briefly. Section 3 describes the TACO-miner algorithm which is applied to extract classification rules from the trained multi-layer perceptrons (MLPs). Section 4 explains the employed data sets and presents the results of the Taguchi design for determining the best parameter settings of MLPs. Comparative results with traditional and some other rule-based classifiers from the literature are also presented in this section. Finally, Section 5 concludes the present work

2. Ant colony and touring ant colony optimization algorithms

Ant colony optimization is a meta-heuristic algorithm which was inspired from the foraging behavior of real ants. ACO algorithm was first introduced by Dorigo and his colleagues as a novel technique for solving hard combinatorial optimization problems in the early 1990s. In the most ant colonies, ants initially explore the area surrounding their nest in a random manner. As soon as ants find food sources, they carry some of the food back to the nest after evaluating the quantity and quality of it. During this return trip,