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Adaptive classification with ellipsoidal regions for multidimensional pattern classification problems

Ki K. Lee *, Wan C. Yoon

Department of Industrial Engineering, Korea Advanced Institute of Science and Technology, 373-1 Gusong-dong, Yusong-gu, Taejon 305-701, Republic of Korea

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Abstract

This paper presents an adaptive classification method that utilizes ellipsoidal regions for multidimensional pattern classification problems with continuous input variables. The classification method fits a finite number of the ellipsoidal regions to data pattern by using adaptive operations iteratively. The method adaptively expands, rotates, shrinks, and/or moves the ellipsoidal regions while each ellipsoidal region is separately handled with a fitness value assigned. The adaptation procedure is combined with a variable selection process in the outer loop, where significant input variables for the ellipsoids are determined by using a stepwise selection method. The performance of the method is evaluated on well-known classification problems from the UCI machine learning repository. The evaluation result shows that the proposed method can exert equivalent or superior performance, with smaller number of rules, to other classification methods such as fuzzy rules, decision trees, or neural networks.

Keywords: Classification; Ellipsoidal regions; Adaptation procedure; Input variable selection

1. Introduction

Classification is a key element to engineering solutions, such as speech recognition, control, tracking, diagnostic applications, and prediction systems where classifiers are often used. This wide range of applicability motivated many researchers to study classification method (Jain et al., 2000; Simpson, 1992). The major objective of classification is to assign a new data object represented as input variables to one of possible classes with a minimal rate of misclassification. Solutions to a classification problem have been characterized in terms of parameterized or non-parameterized separation boundaries. Various approaches are

* Corresponding author. Tel.: +82 42 869 3159; fax: +82 42 869 3110.
E-mail address: kiklee@naver.com (K.K. Lee).

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utilized to design the separation surfaces, depending on the kind of representation method, such as mathematical functions, neural networks, fuzzy if-then rules, and decision trees etc. One of the recent approaches is a regional method, which builds up the separation surfaces by adapting regions of particular shapes to class boundaries of given data. Abe et al. (1999) classified the regions which approximate class boundaries into (1) ellipsoidal regions (Abe et al., 1999; Abe and Thawonmas, 1997); (2) hyperbox regions whose surfaces are parallel to one of the input variables (Abe and Lan, 1995; Simpson, 1992); and polyhedron regions whose surfaces are expressed by a linear combination of input variables (Uebele et al., 1995; Baram, 2000). In (Abe and Thawonmas, 1997), a classifier with ellipsoidal regions was shown to have the generalization ability comparable or superior to those of classifiers with the other shapes.

From the result of Abe and Thawonmas (1997), this paper discusses a classifier with ellipsoidal regions, expecting to attain high interpretability and high tractability in addition to generalization ability. Abe et al. (1999) represented several ellipsoidal clusters by a center and a covariance matrix. Then a fuzzy rule tuning procedure was followed in order to improve classification rate. However, the ellipsoids represented by a center and a covariance matrix have lack of intuitional interpretability, which thus require more computational efforts to construe and manipulate. In this paper we propose ellipsoidal regions, each of which is defined by two foci and a constant, instead of a center and a covariance matrix. The proposed representation facilitates interpreting and handling the ellipsoids due to the analysis by visualization.

This paper presents an adaptive classifier, which approximates training data pattern with the proposed ellipsoidal regions, for pattern classification problems with many continuous input variables. Each ellipsoid, which is assigned to a class among given classes, performs the adaptive procedure by appropriately moving, rotating, extending, or shrinking the ellipsoid itself according to the current state of the ellipsoid. The state of an ellipsoid is represented by a fitness value, which is calculated from the class distribution of data located in the ellipsoid region. The details about the fitness value are explained in later section. The main idea of the adaptive procedure is to have the ellipsoid with high fitness values expanded in expectation of increase in the fitness value. On the other hand, the ellipsoid with low fitness value, due to existence of different class data, tries to avoid the different class data by move, rotation, or shrinkage.

A selection of input variable is also combined with the adaptive classification method to improve the effectiveness of the resulting classifier. A discriminatory variable subset simplifies both the pattern representation and the classifiers that are built on the selected variables. Consequently, the resulting classifier will be faster, will use less memory, and will have more robust performance. To obtain the advantages of the input variable selection, we adopt a combined stepwise selection and elimination. The stepwise method is a widely-used variable selection technique that yields good results relative to its search time (Weiss and Kulikowski, 1991). In our variable selection method, salient variables are added and less discriminatory variables deleted in an iterative manner. The detailed procedure will be described in later section.

Section 2 presents a classification method using an adaptation procedure to fit ellipsoids to the pattern of training samples. Section 3 describes the input variable selection method that finds the appropriate subset of variables among all the possible variables for a classifier. Section 4 gives an illustrative example and investigates the performance of the classification method by applying it to four well-known classification data sets. These data sets are widely used for comparing various pattern classification methods. Section 5 gives the conclusion.

2. Classification using an adaptation procedure with ellipsoidal regions

2.1. Pattern classification problem

Let us assume that our pattern classification problem has c classes in the n-dimensional pattern space $[0,1]^n$ with continuous input variables. It is also supposed that a finite set of points $X = \{\boldsymbol{x}_p,$