Artificial Intelligence in Medicine (2009) **47**, 25—41

ELSEVIER

ARTIFICIAL INTELLIGENCE IN MEDICINE

http://www.intl.elsevierhealth.com/journals/aiim

An interpretable fuzzy rule-based classification methodology for medical diagnosis

Ioannis Gadaras *, Ludmil Mikhailov

University of Manchester, School of Computer Science, Manchester, M13 9EP, United Kingdom

Received 14 May 2008; received in revised form 5 May 2009; accepted 10 May 2009

KEYWORDS
Fuzzy rule extraction from data;
Hierarchical and flexible input partitioning;
Interpretable and scalable knowledge;
Medical diagnosis

Summary

Objective: The aim of this paper is to present a novel fuzzy classification framework for the automatic extraction of fuzzy rules from labeled numerical data, for the development of efficient medical diagnosis systems.

Methods and materials: The proposed methodology focuses on the accuracy and interpretability of the generated knowledge that is produced by an iterative, flexible and meaningful input partitioning mechanism. The generated hierarchical fuzzy rule structure is composed by linguistic; multiple consequent fuzzy rules that considerably affect the model comprehensibility.

Results and conclusion: The performance of the proposed method is tested on three medical pattern classification problems and the obtained results are compared against other existing methods. It is shown that the proposed variable input partitioning leads to a flexible decision making framework and fairly accurate results with a small number of rules and a simple, fast and robust training process.

1. Introduction

Over the last decades, there have been numerous implementations of computer systems in medicine [1]. Despite the increasing scientific evolution of both information technology and medicine, the inherent uncertainty of the latter makes the fusion of these technologies a rather difficult task. The main sources of this natural imprecision are due to the insufficient understanding of biological mechanisms and their interactions, and the ambiguity of medical results and measurements. Furthermore, many diseases appear in multiple stages, in combination with other similar disorders and with different symptoms of variable extension and sequence. Therefore, it would be essential and very beneficial to ensure fast, accurate and meaningful diagnosis for a number of widespread and fatal diseases. That would additionally improve the effectiveness of medical treatment as well as the speed and accu-

* Corresponding author at: Flat 41, Trinity Court, Higher Cambridge St. 41, Manchester, M1 6AR, United Kingdom.
Tel.: +44 7737 53 0964/161 306 3361; fax: +44 161 306 3518.
E-mail addresses: i.gadaras@student.manchester.ac.uk (I. Gadaras), ludi.mikhailov@manchester.ac.uk (L. Mikhailov).

0933-3657/$ — see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.artmed.2009.05.003

racy of the remedy reaction, affecting the recovery and life expectancy of the patient and the operational efficiency of the medical units.

If we additionally consider the increasingly growing amount of various collected medical data, we can easily appreciate the necessity of its categorization and the expediency of such a classification framework.

The natural evolution of various diseases, the obscure nature of medical data and the intrinsic ambiguity of medical problems require a consistent framework that can handle uncertainty by allowing variable and multiple class memberships and facilitating approximate reasoning. This inevitably makes the fuzzy logic (FL) a valuable tool for depicting medical concepts by treating them as fuzzy sets [2]. In addition, the FL and the utilization of linguistic/fuzzy variables provide a rigorous framework for verbal representation of numerical concepts that can be then embedded in meaningful fuzzy rules. Such rules can be easily comprehended, verified, tuned and possibly expanded by medical experts, and used for the development of classification systems that can be very valuable in the process of medical diagnosis.

Each fuzzy variable is composed of a set of membership functions that determine the degree of fitness of numerical examples to each particular fuzzy set. This way, the FL can represent variable degrees of an illness and symptoms via multiple class memberships and provide an approximate but verbally consistent and accurate inference process.

Two main factors are proved to be critical for the success of any medical diagnosis process, based on fuzzy reasoning:

1. A fast and accurate input partitioning method that attempts to find the soft class boundaries by automatically processing a series of representative examples.
2. A verbally interpretable knowledge representation framework that allows the verification and integration of the generated rules.

In this paper we treat the medical diagnosis as a pattern classification problem and try to match symptoms against diseases by learning from medical data. Thus we can classify potential patients according to numerical values of their symptoms and their degrees of membership in various classes, which are represented as fuzzy sets.

The proposed classification methodology initially identifies fuzzy boundaries of the classes by processing a set of labeled data. Exploring the characteristics of the identified boundaries, membership functions for each class are automatically produced and corresponding fuzzy rules are obtained. When new patterns need to be classified, their numerical attributes are tested against generated knowledge in order to match the symptoms with a rule's antecedent. When that happens, the appropriate rule is executed to identify the most appropriate class.

The paper is structured as follows. In the next section some related methods and technologies are shortly presented. The proposed fuzzy classification method is described in Section 3. Section 4 presents some numerical results of the proposed method against three different medical datasets, followed by the conclusions in Section 5.

2. Related technologies

One of the earliest attempts to formalize medical diagnosis applications was based on a pattern classification approach to identify the decision boundaries of various diseases from data [3]. Expert systems [4,5] were introduced soon after with MYCIN [6], a medical knowledge based system that was using certainty factors to express uncertainty.

The FL was applied in medical systems [7], almost 20 years after its introduction by Zadeh [8], but has recently given birth to various interesting implementations [9,10]. Most of them employ fuzzy clustering algorithms [11] or connectionist neuro-fuzzy methodologies [12] to separate the input space and automatically extract fuzzy rules directly from data. However, those methods have a number of critical disadvantages. Clustering algorithms do not use class labels but usually a gain/loss objective function, yielding sometimes suboptimum results that are sometimes vulnerable to parameters initialization [13,14]. On the other hand, neural learning is usually slow, order dependent and incomprehensible, since the extracted knowledge is represented in terms of numerical weights.

Genetic algorithms (GA) and genetic programming emerged four decades ago but have been recently proven to be fairly successful and popular [15,16]. The GA mimic the process of natural evolution, using the survival of the fittest and natural selection principles for tackling classification/optimization problems. Most of GA perform exhaustive search iterations on a population of candidate results and select a competitive set each time. They attempt to obtain an optimum result by swapping parts, selectively mutating chromosomes that encode the solution and evaluate candidate combinations against a fitness function. This procedure has been proved to be effective, as it is used in natural evolution and is extensively used in fuzzy-genetic applications, however it is usually slow due