

Fuzzy Logic Applied to Biomedical Image Analysis

Alfonso Castro

University of A Coruña, Spain

Bernardino Arcay

University of A Coruña, Spain

INTRODUCTION

Ever since Zadeh established the basis of fuzzy logic in his famous article Fuzzy Sets (Zadeh, 1965), an increasing number of research areas have used his technique to solve and model problems and apply it, mainly, to control systems. This proliferation is largely due to the good results in classifying the ambiguous information that is typical of complex systems. Success in this field has been so overwhelming that it can be found in many industrial developments of the last decade: control of the Sendai train (Yasunobu & Miyamoto, 1985), control of air-conditioning systems, washing machines, auto-focus in cameras, industrial robots, etc. (Shaw, 1998)

Fuzzy logic has also been applied to computerized image analysis (Bezdek & Keller & Krishnapuram & Pal, 1999) because of its particular virtues: high noise insensitivity and the ability to easily handle multidimensional information (Sutton & Bezdek & Cahoon, 1999), features that are present in most digital images analyses. In fuzzy logic, the techniques that have been most often applied to image analysis have been fuzzy clustering algorithms, ever since Bezdek proposed them in the seventies (Bezdek, 1973). This technique has evolved continuously towards correcting the problems of the initial algorithms and obtaining a better classification: techniques for a better initialization of these algorithms, and algorithms that would allow the evaluation of the solution by means of validity functions. Also, the classification mechanism was improved by modifying the membership function of the algorithm, allowing it to present an adaptative behaviour; recently, kernel functions were applied to the calculation of memberships. (Zhong & Wei & Jian, 2003)

At the present moment, applications of fuzzy logic are found in nearly all Computer Sciences fields, it constitutes one of the most promising branches of Artificial

Intelligence both from a theoretic and commercial point of view. A proof of this evolution is the development of intelligent systems based on fuzzy logic.

This article presents several fuzzy clustering algorithms applied to medical images analysis. We also include the results of a study that uses biomedical images to illustrate the mentioned concepts and techniques.

BACKGROUND

Fuzzy logic is an extension of the traditional binary logic that allows us to achieve multi-evaluated logic by describing domains in a much more detailed manner and by classifying better through searches in a more extensive area. Fuzzy logic makes it possible to model the real world more efficiently: for example, whereas binary logic merely allows us to state that a coffee is hot or cold, fuzzy logic allows us to distinguish between all the possible temperature fluctuations: very hot, lukewarm, cold, very cold, etc.

Techniques based on fuzzy logic have proven to be very useful for dealing with the ambiguity and vagueness that are normally associated to digital images analysis. At what grey level do we fixate the thresholding? Where do we locate the edge in blurred objects? When is a grey level high, low, or average?

The fuzzy processing of digital images can be considered a totally different focus with respect to the traditional computerized vision techniques. It was not developed to solve a specific problem, but describes a new class of image processing techniques and a new methodology to develop them: fuzzy edge detectors, fuzzy geometric operators, fuzzy morphological operators, etc.

These features make fuzzy logic especially useful for the development of algorithms that improve medical images analysis, because it provides a framework

for the representation of knowledge that can be used in any phase of the analysis. (Wu & Agam & Roy & Armato, 2004) (Vermandel & Betrouni & Taschner & Vasseu & Rosseau, 2007)

FUZZY CLUSTERING ALGORITHMS APPLIED TO BIOMEDICAL IMAGE ANALYSIS

Medical imaging systems use a series of sensors that detect the features of the tissues and the structure of the organs, which allows us, depending on the used technique, to obtain a great amount of information and images of the area from different angles. These virtues have converted them into one of the most popular support techniques in diagnosis, and have given rise to the current distribution and variety in medical images modalities (X-Rays, PET ...) and to new modalities that are being developed (fMRI).

The complexity of the segmentation of biomedical images is entirely due to its characteristics: the large amount of data that need to be analyzed, the loss of information associated to the transition from a 3D body to a 2D representation, the great variability and complexity of the shapes that must be analyzed ... Among the most frequently applied focuses to segment medical images is the use of pattern recognition techniques, since normally the purpose of analyzing a medical digital image is the detection of a particular element or object: tumors, organs, etc.

Of all these techniques, fuzzy clustering techniques have proven to be among the most powerful ones, because they allow us to use several features of the dataset, each with their own dimensionality, and to partition these data; also, they work automatically and usually have low computational requirements. Therefore, if the problem of segmentation is defined as the partition of the image into regions that have a common feature, fuzzy clustering algorithms carry out this partition with a set of exemplary elements, called centroids, and obtain a matrix of the size of the original image and with a dimensionality equal to the number of clusters into which the image was divided; this indicates the membership of each pixel to each cluster and serves as a basis for the detection of each element.

In the next section we present a series of fuzzy clustering algorithms that can be considered to reflect the evolution in this field and its various viewpoints.

Finally, these algorithms will be used in a study that shows the use and possibilities of fuzzy logic in the analysis of biomedical images.

Fuzzy C-Means (FCM)

The FCM algorithm was developed by Bezdek (Bezdek, 1973) and is the first fuzzy clustering algorithm; it initially needs the number of clusters in which the image will be divided and a sample of each cluster. The steps of this algorithm are the following:

1. Calculation of the membership of each element to each cluster:

$$u_k(i, j) = \left(\frac{\|y(i, j) - v_k\|^{\frac{2}{m-1}}}{\sum \|y(i, j) - v_j\|^{\frac{2}{m-1}}} \right)^{-1} \quad (1)$$

2. Calculation of the new centroids of the image:

$$v_k = \frac{\sum_{i,j} u_k(i, j)^m y(i, j)}{\sum_{i,j} u_k(i, j)^m}, k = 1, \dots, C \quad (2)$$

3. If the error stays below a determined threshold, stop. In the contrary case, return to step 1.

The parameters that were varied in the analysis of the algorithm were the provided samples and the value of m .

Fuzzy K-Nearest Neighbour (FKNN)

The Fuzzy K-Nearest Neighbour (Givens Jr. & Gray & Keller, 1992) is, as its name indicates, a fuzzy variant of a hard segmentation algorithm. It needs to know the number of classes into which the set that must be classified will be divided.

The element that must be classified is associated to the class of the nearest sample among the K most similar ones. These K most similar samples are known as "neighbours"; if, for instance, the neighbours are classified from more to less similar, the destination class of the studied element will be the class of the neighbour that is first on the list.

We use the expression in Equation 3 to calculate the membership factors of the pixel to the considered clusters:

7 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage: www.igi-global.com/chapter/fuzzy-logic-applied-biomedical-image/10323

Related Content

IoT-Based Dynamic Traffic Management and Control for Smart City in India

Deepali Kothari, Anjana Jain and Arun Parakh (2021). *Computational Methodologies for Electrical and Electronics Engineers* (pp. 127-139).

www.irma-international.org/chapter/iot-based-dynamic-traffic-management-and-control-for-smart-city-in-india/273840

Object Recognition Pipeline: Grasping in Domestic Environments

John Alejandro Castro Vargas, Alberto Garcia Garcia, Sergiu Oprea, Sergio Orts Escolano and Jose Garcia Rodriguez (2018). *Advancements in Computer Vision and Image Processing* (pp. 18-33).

www.irma-international.org/chapter/object-recognition-pipeline/201780

Applications of Fuzzy Logic to Systems' Modelling

Michael Gr. Voskoglou (2013). *International Journal of Fuzzy System Applications* (pp. 1-15).

www.irma-international.org/article/applications-fuzzy-logic-systems-modelling/77859

Privacy-Centric Approach in Leveraging Federated Learning for Improved Parkinson's Disease Diagnosis

Rujuta Amit Joshi, Shlok Rahul Mangle, Neha Katre and Harshal Dalvi (2024). *Pioneering Smart Healthcare 5.0 with IoT, Federated Learning, and Cloud Security* (pp. 130-151).

www.irma-international.org/chapter/privacy-centric-approach-in-leveraging-federated-learning-for-improved-parkinsons-disease-diagnosis/339431

Improving Learning Outcomes for Higher Education Through Smart Technology

James O. Connelly and Paula Miller (2018). *International Journal of Conceptual Structures and Smart Applications* (pp. 1-17).

www.irma-international.org/article/improving-learning-outcomes-for-higher-education-through-smart-technology/206903