Fuzzy and Deep Fuzzy Logic, application to image processing, clustering and time series analysis

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I. Introduction

In this work, we will describe and use two fuzzy algorithms, Fuzzy-Cmeans and Adaptative Neuro-Fuzzy Inference Systems (ANFIS) on images and time series. Our code and implementations are available on our GitHub[1]. In a first part we will describe the Fuzzy-Cmeans algorithm while in a second part we will talk about fuzzy neural net and more precisely about ANFIS. Finally, we will conclude our work with a discussion dealing with some considerations on the current state of research on Fuzzy Logic compared to deep learning but also to other mathematical approaches increasingly used to solve diverse optimization problems.

II. Fuzzy-Cmeans

Fuzzy-Cmeans or Fuzzy-C was first proposed by J. C. Dunn in 1973 [1] and further improved by Jim Bezdek in 1981 [2]. This algorithm has recently been used in multiple domain of applications such as clustering on genomic datas [3] or segmentation of MRI scans [4]. In addition, derivatives of this algorithm exist and have been used in recent works like Intuitionist Fuzzy-Cmeans and Possibilistic Fuzzy-Cmeans apparently providing better results than the original algorithm especially in handling outliers [5]. Fuzzy-Cmeans is a density-based iterative clustering algorithm. For each point, pixels or set of numbers, a membership function is assigned to them that indicates whether they have a strong or weak association to a given cluster. The membership value of the data points for each cluster will then be updated on each iteration. The algorithm minimizes a chosen criterion of association with respect to the degree of membership U_{ij} and a distance metric d_{ij} which represents the distance between the objects and the corresponding cluster as indicated in **Equation 1**. The number of clusters is chosen before training. The time complexity of the algorithm is *Near O(N)*.

$$\sum_{i=1}^{n}\sum_{j=1}^{k} u_{ij}^{m}\, d\left(\vec{X}_i, \vec{C}_j\right), \quad 1 < m < \infty$$

Equation 1. Objective function to minimize.

In the above function, m is a real number superior to 1, u_{ij} being the degree of membership of X_i in the cluster j, X_i is the i_{th} of d-dimensional measured data measured data, C_j is the d-dimension of the center of the cluster and $d()$ refers to any distance or error measure that express similarity between the data and the centers.

[1] https://github.com/clementsiegrist/reco_formes

III. ANFIS: Adaptative Neuro-Fuzzy Inference Systems

Though early theoretical proposals were made by S. Lee in the mid 70s [6], fuzzy neural networks were first proposed and designed in the early/mid 90s for modelling and control purposed, especially by researchers whose main domain of expertise was fuzzy logic [7][8][9][10].

Adaptative Neuro-Fuzzy Inference Systems (ANFIS) is a class of adaptative networks that are functionally equivalent to fuzzy inference system and have been proposed for the first time by J.-S. R. Jang [11] and subsequently detailed and explored in depth in [12]. It has been used primarily in order to predict nonlinear components in an on-line control system and in order to predict pseudo-chaotic time series [13]. Recent works have applied ANFIS or derivatives of it with wavelets and genetic algorithms to a lot of uses such as on multiple or single mobile robots navigation [14][15] and classification problems [16] and short term load prediction [17] to name only a few. More details about the diverse recent uses and application of ANFIS and its derivatives are available in [18].

An adaptative network is a neural network type-like structure consisting of nodes and directional links through which the nodes are connected. In addition, part or all the nodes are adaptative meaning that their outputs are conditioned to the parameters pertained to these nodes and the learning rules specifying how these parameters must be modified in order to minimize a given error measure. More precisely, the network has square and circle nodes as shown in **Figure 2**. A square node (adaptative node) has parameters while a circle node (fixe node) has none. Note that the links in an adaptative network only indicate the flow direction of signals between nodes; no weights are associated with the links as shown in **Figure 2**.

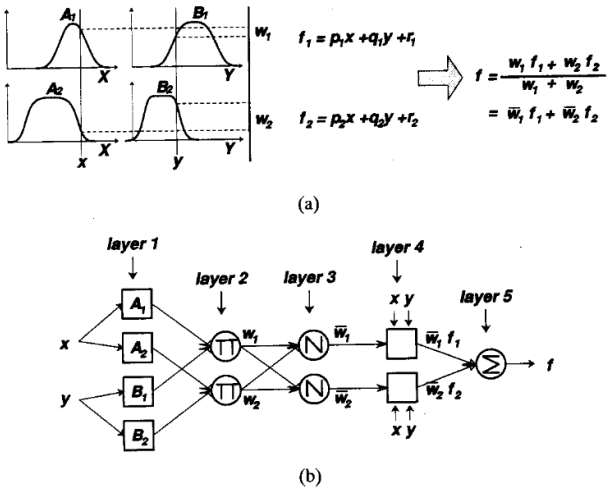

Figure 1. (*a*) A two-input first-order Sugeno fuzzy model with two rules; (*b*) equivalent ANFIS architecture.

Another difference between ANFIS and a simple Perceptron (Feed-Forward Neural Network) is the following: rather than initializing weights for each neuron according to some distributions, each neuron will be initialized with a chosen membership function: gauss, sigmoid, bell, trapezoidal or triangular following some given rules. In this approach, while premise parameters are determined by using gradient descent (GD), consequence parameters are found out with least squares estimation (LSE) method.

IV. Results

Detailed results and visualization are available on our github[2].

Discussion

Though Fuzzy Logic is a promising and already used and proven mathematical approach which can clearly compete, complement and maybe overcome deep learning on some applications, it still lacks golden standard frameworks and library like those used for deep learning like Keras, TensorFlow and Pytorch, even though some open-source libraries and GitHub [19] exist and aggregate some code[3]. Moreover, it is not the only domain of research that can

[2] https://github.com/clementsiegrist/reco_formes

[3] https://github.com/Apress/deep-neuro-fuzzy-systems-w-python

compete with deep learning to solve advanced optimization problems. Indeed, genetic and biological algorithms are increasingly used and are becoming trendy again with new frameworks being available [20] and benchmarks [21] having been recently published. In addition, other mathematical approaches like geometrical deep-learning with Riemannian Neural Networks are emerging and increasingly being used in the industry [22][23] with usable frameworks already existing [24], though the maturity of these approaches is still not completely proven.

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