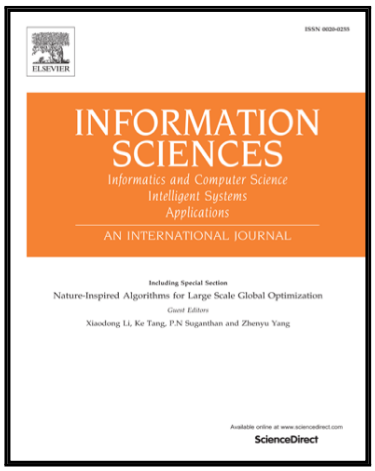


# Deep Rule-Based Classifier with Human-level Performance and Characteristics

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# Deep Rule-Based Classifier with Human-level Performance and Characteristics

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**Abstract-** In this paper, a new type of multilayer rule-based classifier is proposed and applied to image classification problems. The proposed approach is entirely data-driven and fully automatic. It is generic and can be applied to various classification and prediction problems, but in this paper we focus on image processing, in particular. The core of the classifier is a fully interpretable, understandable, self-organised set of IF…THEN… fuzzy rules based on the prototypes autonomously identified by using a one-pass type training process. The classifier can self-evolve and be updated continuously without a full retraining. Due to the prototype-based nature, it is non-parametric; its training process is non-iterative, highly parallelizable and computationally efficient. At the same time, the proposed approach is able to achieve very high classification accuracy on various benchmark datasets surpassing most of the published methods, be comparable with the human abilities. In addition, it can start classification from the first image of each class in the same way as humans do, which makes the proposed classifier suitable for real-time applications. Numerical examples of benchmark image processing demonstrate the merits of the proposed approach.

**Keywords-** fuzzy rule based classifiers, deep learning, non-parametric, non-iterative, self-evolving structure

## 1. Introduction

Nowadays, deep learning has gained a lot of popularity in both the academic circles and the general public thanks to the very quick advance in computational resources (both hardware and software) [20], [26]. A number of publications have demonstrated that deep convolutional neural networks (DCNNs) can produce highly accurate results in various image processing problems including, but not limited to, handwritten digits recognition [12], [13], [21], [40], object recognition [18], [23], [42], human action recognition [10], [41], human face recognition [19], [33], [46], remote sensing image classification [44], [50], etc. Some publications suggest that the DCNNs can match the human performance on handwritten digits recognition problems [12], [13]. Indeed, DCNN is a powerful technique that provides high classification rates. There are also recently introduced approaches exploiting deep models for image understanding [31], [32] by learning informative hidden representations from visual features of images through DCNNs.

However, DCNNs have a number of deficiencies and shortcomings. For example, they require a huge amount of training data, are usually offline, lack transparency and their internal parameters cannot be easily interpreted; they involve *ad hoc* decisions concerning the internal structure; they have no proven guaranteed convergence; they have limited parallelization ability. It is also well-known that DCNN-based approaches are not able to deal with uncertainty. They perform classification quite well when the validation images share similar feature properties with the training images, however, they require a full retraining for images from unseen classes as well as for images with feature properties different from that of the training images.

On the other hand, traditional fuzzy rule-based (FRB) systems are well known for being an efficient approach to deal with uncertainties. FRB systems have been successfully used for classification [8], [24] offering transparent and interpretable structure. Their design also traditionally requires handcrafting membership functions, assumptions to be made and parameters to be selected. More recently, very efficient data-driven FRB classifiers were proposed which can learn autonomously from the data (streams) [2], [8], and self-evolve, however even they could not reach the levels of performance achieved by deep learning classifiers mainly because of their quite simple and small internal structure.

In this paper, we offer a principally new approach, which combines the advantages of both, the recently introduced self-organising non-parametric FRB systems [2], [7], , applied to classification problem [3] with the concept of a massively parallel multi-layer structure that deep learning benefits from. This results in a principally new type of a multi-layer neuro-fuzzy architecture, which we call Deep Rule-Based (DRB) system and demonstrate its performance on various image classification problems. The proposed DRB approach

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