Guest Editorial: Deep Fuzzy Models

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DEEP learning has gained significant attention within the computational intelligence community in recent years. Its success has been mainly due to the increased power of modern computational platforms in terms of their ability to collect, store and process large volumes of data. This has led to a substantial increase in the effectiveness and efficiency of data management. As a result, it has become possible to achieve high accuracy for some benchmark learning tasks such as object classification and image recognition within a short time frame. The most common implementation of deep learning has been through neural networks due to the ability of their layers of neurons to perform multiple functional composition as part of a multistage learning process.

In spite of the significant recent advances in deep learning, there are still some unsolved problems and significant limitations. In particular, effectiveness is usually compromised when the data is not well defined due to noise, uncertainty, ambiguity, vagueness and incompleteness. This has an adverse impact on efficiency due to the necessity to define the data better by means of additional collection, analysis and cleaning. The reduced effectiveness and efficiency undermine the ability of deep learning to address some safety and time critical tasks. Besides this, deep learning has been used mainly in a passive manner for environmental monitoring but it has rarely been used in an active manner for environmental control. Finally, deep learning models often have poor transparency which makes them difficult for understanding and interpretation by non-technical users.

This special issue features recent developments and emerging topics in the area of deep fuzzy models that address some of the problems and limitations above. These models have been known under different names such as hierarchical fuzzy systems and fuzzy networks. They are usually well suited for performing multiple functional composition at either crisp or linguistic level. Moreover, they have the potential of handling effectively and efficiently data that is not well defined by means of a fuzzy approach. Also, deep fuzzy models can be used in both passive and active manner with regard to the environment due to their generic structure. Finally, these models have a fairly high level of transparency due to their rule base nature.

A total of 25 papers have been accepted for publication in this special issue. The papers can be broadly classified in two major groups in terms of their general focus and novelty aspects - theoretical and applied. The group of theoretical papers can be divided in the following two subgroups: 'Systems and Networks' and 'Training and Learning'. Likewise, the group of applied papers can be divided in the following two subgroups: 'Classification and Clustering' and 'Decision and Control'. It should be noted that these four subgroups of papers have partial overlap as many of the topics covered are interrelated.

The subgroup 'Systems and Networks' includes 7 papers. The paper 'Data Processing Technique for Neural Networks Based on Image Represented by a Fuzzy Function' proposes a human perception motivated pre-processing technique that enriches the original image data using local intensity information. This technique decreases the classification error in comparison to most established methods. The paper 'Deep Fuzzy Echo State Networks for Machinery Fault Diagnosis' proposes a novel deep learning method for improving feature extraction with less computational burden by means of layer-wise fuzzy tuning. This method improves learning efficiency and robustness in comparison to most established methods while overcoming the vanishing gradient problem of deep learning. The paper 'Passivity and Passification for Switched T-S Fuzzy Systems with Sampled Data Implementation' proposes a switching law that requires the values of system states only at discrete sampling instants. This law reduces the switching frequency and avoids the occurrence of chattering behaviour in comparison to most established methods. The paper 'Neural Network Approach to Solving Fuzzy Nonlinear Equations using Z-Numbers' proposes a novel deep multilevel neural network that is trained using backpropagation to derive the Z-number coefficients for fuzzy equational models of uncertain nonlinear systems. The network reduces the value of the error function in comparison to most established methods. The paper 'Lip Image Segmentation Based on a Fuzzy Convolutional Neural Network' proposes a deep fuzzy neural network that combines fuzzy units for handling uncertainty and convolutional units for extracting discriminative features. The proposed network improves pixel-wise accuracy in comparison to most established methods. The paper 'A Deep Fuzzy Neural Network with Sparse Autoencoder for Emotional Intention Understanding in Human Robot Interaction' proposes a novel deep fuzzy neural network that uses fuzzy c-means for input data clustering and dimensionality reduction. The network improves the accuracy of emotional intention understanding in comparison to most established methods. The paper 'Hierarchical Fuzzy Opinion Neural Networks: Top-Down for Social Organizations and Bottom-Up for Election' proposes

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two novel networks: a top-down network for modelling the propagation of opinions of leaders within social organizations and a bottom-up network for modelling the agglomeration of opinions of multiple agents into a consensus. The networks have a higher speed of convergence in comparison to most established methods.

The subgroup 'Training and Learning' includes 5 papers. The paper 'Biologically Plausible Fuzzy-Knowledge-Out and Its Induced Wide Learning of Interpretable TSK Fuzzy Classifiers' proposes a design methodology that is inspired by the drop-out concept in deep learning. The proposed methodology provides higher classification accuracy and interpretability in comparison to most existing methods. The paper 'Enabling Explainable Fusion in Deep Learning with Fuzzy Integral Neural Networks' proposes a technique for representing a powerful nonlinear aggregation function Fuzzy Choquet Integral as a multi-layer network. The technique provides higher accuracy and explainability in comparison to most existing methods. The paper 'Fast Training Algorithms for Deep Convolutional Fuzzy Systems with Application to Stock Index Prediction' proposes a methodology for representing a high-dimensional input space as a multi-layer interconnected structure of low-dimensional fuzzy systems whose input variables are selected through a moving window across the input spaces of the individual layers. The methodology provides higher efficiency, interpretibilty and flexibility in comparison to most existing methods. The paper 'An Incremental Construction of Deep Neuro Fuzzy System for Continual Learning of Non-stationary Data Streams' proposes a deep evolving fuzzy neural network whose fuzzy rules can be automatically extracted from data streams or removed. The network provides higher classification accuracy in comparison to most established methods. The paper 'DeepBalance: Deep Learning and Fuzzy Oversampling for Vulnerability Detection' proposes a system that combines the concepts of deep code representation learning and fuzzy based class rebalancing. The system provides higher vulnerabililty detection accuracy in comparison to most established methods.

The subgroup 'Classification and Clustering' includes 7 papers. The paper 'A Fuzzy Deep Model Based on Fuzzy Restricted Bolzmann Machines for High Dimensional Data Classification' proposes a learning approach that is divided into a pre-training phase and a fine-tuning phase with a resulting model of generative or discriminative type. The proposed approach handles directly high-dimensional raw images and outperforms most benchmark methods in terms of classification accuracy. The paper 'Fuzzy Multilayer Clustering and Fuzzy Label Regularization for Unsupervised Person Re-identification' proposes a method for unsupervised person re-identification that learns a new feature space using a multilayer perceptron for clustering to overcome the influence of complex pedestrian images. The method reduces the risk of over-fitting by regularizing the training process and outperforms most benchmark methods in terms of identification accuracy. The paper 'A Novel Deep Fuzzy Classifier by Stacking Adversarial Interpretable TSK Fuzzy Sub-classifiers with Smooth Gradient Information' proposes a method for classification with if-parts of first-order fuzzy rules that are generated by random selection of fixed linguistic terms along each feature. The method improves the efficiency of the training process and outperforms most benchmark methods in terms of classification accuracy. The paper 'Time Series Classification using Fuzzy Cognitive Maps' proposes a method for classification that distinguishes maps constructed for time series belonging to different classes. The method provides a more adequate representation of time series and outperforms most benchmark methods in terms of classification accuracy. The paper 'Deep Fuzzy Tree for Large-Scale Hierarchical Visual Classification' proposes a model for classification that is based on fuzzy rough set theory and provides a replacement for the soft-max layer in deep learning for classifying visual samples after feature extraction. The model improves the label structure and outperforms most benchmark methods in terms of classification accuracy and efficiency. The paper 'Interpretable Deep Convolutional Fuzzy Classifier' proposes an architecture that first employs a convolutional neural network as an automated feature extractor and then performs fuzzy clustering in the derived feature space. The architecture provides better explainability and outperforms most benchmark methods in terms of classification accuracy. The paper 'Deep Fuzzy Clustering – A Representation Learning Approach' proposes a method for handling real high-dimensional data with complex latent distribution by representing the data in a feature space produced by a deep neural network. The method enhances the friendly representation and outperforms most benchmark methods in terms of clustering accuracy.

The subgroup 'Decision and Control' includes 6 papers. The paper 'Interval Type-2 Fuzzy Sampled-Data H-Infinity Control for Nonlinear Unreliable Networked Control Systems' proposes a method for systems with parameter uncertainties, data dropout and transmission delay. The method improves the control performance and is superior to most baseline methods in terms of tracking accuracy. The paper 'A New Method for Group Decision making with Hesitant Fuzzy Preference Relations Based on Multiplicative Consistency' proposes a method with a multi-stage structure that considers multiplicative consistency and consensus simultaneously. The method improves the effectiveness of the decision making and is superior to most baseline methods in terms of consistency. The paper 'Fuzzy Fixed-Time Learning Control with Saturated Input, Nonlinear Switching Surface and Switching Gain to Achieve Null Tracking Error' proposes a method with multi-layer structure that is based on a class of passive and distributive models with uncertainties. The method has improved computational efficiency and is superior to most baseline methods in terms of tracking accuracy. The paper 'EFMCDM: Evidential Fuzzy Multicriteria Decision Making Based on Belief Entropy' proposes a method with multi-stage structure

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that integrates Dempster-Shafer theory with belief entropy by modelling each criterion as evidence. The method improves the robustness of the decision making and is superior to most baseline methods in terms of consistency. The paper 'Online Deep Fuzzy Learning for Control of Nonlinear Systems Using Expert Knowledge' proposes a method with an off-line pre-training stage and on-line post-training stage by combining deep learning with fuzzy logic. The method improves the control performance and is superior to most baseline methods in terms of tracking accuracy. The paper 'Robust Fuzzy Predictive Control for Discrete-Time Systems with Interval Time-Varying Delays and Unknown Disturbances' proposes a method with multi-level structure that first builds a T-S fuzzy model by a number of linear sub-models and nonlinear membership functions and then introduces an augmented state space to independently regulate the process state variables. The proposed method improves the control performance and is superior to most baseline methods in terms of tracking accuracy.

We would like to take this opportunity to thank all authors of submitted papers for responding to the announcement for this special issue and sharing their research results. We would also like to thank the reviewers for the valuable comments and feedback provided on the contents of these papers. In addition, we would like to express our thanks to the Editor-In-Chief for the journal, Prof Jonathan Garibaldi, and the Journal Administrator, Clair Morton, for their support and assistance. Finally, we would like to dedicate this special issue to Prof Robert John, Special Issue Editor for the journal, who has been an inspirational visionary for the fuzzy community.

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