Guest Editorial
Evolutionary Computation Meets Deep Learning

DEEP learning is a timely research direction in machine learning, where breakthrough progress has been made in both academe and industries, bringing promising results in speech recognition, computer vision, industrial control and automation, etc. The motivation of deep learning is primarily to establish a model to simulate the neural connection structure of the human brain. While dealing with complex tasks, deep learning adopts a number of transformation stages to deliver the in-depth description and interpretation of the data. Deep learning achieves exceptional power and flexibility by learning to represent the task through a nested hierarchy of layers, with more abstract representations formed successively in terms of less abstract ones. One of the key issues of existing deep learning approaches is that the meaningful representations can be learned only when their hyperparameter settings are properly specified beforehand, and general parameters are learned during the training process. Until now, not much research has been dedicated to automatically set the hyperparameters, and accurately find the globally optimal general parameters. However, this problem can be formulated as optimization problems, including discrete optimization, constrained optimization, large-scale global optimization, and multiobjective optimization, by engaging mechanisms of evolutionary computation.

For more than three decades, evolutionary computation and various metaheuristic techniques have shown powerful abilities and superiority in addressing real-world discrete, constrained, large-scale, and multiobjective optimization problems. Evolutionary computation for deep learning aims at solving the optimization problems involved in deep learning algorithms. Their learning and adaptation capabilities enable structure and parameter optimization of deep learning systems for different kinds of machine learning tasks, such as clustering, classification, regression, rule mining, and many others. Their flexible frameworks also enable handling multiple objectives simultaneously, e.g., accuracy and interpretability maximization, and many different aspects of data types like imbalanced, incomplete, and privacy-preserving data sets. Evolutionary computation can be efficiently used in deep learning to address complex and challenging issues. Deep learning approaches with evolutionary computation have frequently been used in a large variety of applications and have started to address complex and challenging issues in deep learning.

Keeping the above objectives in mind, following a stringent review process, nine articles for this special issue of the IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTING include nine articles, that represent some of the latest developments in the emerging areas of evolutionary computation for deep learning. For the record, a total of 43 submissions were received in response to the open call. These articles were rigorously evaluated according to the normal reviewing process, which took into consideration factors of originality, technical quality, presentational quality, and overall contribution. Nine articles provide a highly interesting and representative view of the current research and potential avenues of evolutionary computation techniques for deep learning, as described in the following.

The article titled "Evolving Deep Convolutional Variational Autoencoders for Image Classification" by Chen *et al.* proposes a novel method to automatically design optimal architectures of variational autoencoders for image classification, called evolving deep convolutional variational autoencoder (EvoVAE), based on a genetic algorithm (GA). In the proposed EvoVAE algorithm, the traditional variational autoencoders are first generalized to a more generic and asymmetrical one with four different blocks, and then a variable length gene encoding mechanism of the GA is presented to search for the optimal network depth. Furthermore, an effective genetic operator is designed to adapt to the proposed variable-length gene encoding strategy. Experimental results reveal the superiority of the proposed EvoVAE algorithm, which outperforms the best competitors

The article titled "AS-NAS: Adaptive Scalable Neural Architecture Search With Reinforced Evolutionary Algorithm for Deep Learning" by Zhang *et al.* proposes an adaptive scalable neural architecture search method (AS-NAS) based on the reinforced evolutionary algorithm (EA) and variable architecture encoding strategy. The distinctive of this work can be summarized as two aspects: 1) a simplified RL algorithm is developed and used as the reinforced operator controller to adaptively select the efficient operators of I-Ching divination EA (IDEA), which can enhance its search efficiency with lower computational cost and 2) a variable-architecture encoding strategy is proposed to encode the neural architecture as a fixed-length binary string. By simultaneously considering variable layers, channels, and connections between different convolution layers, the deep neural architecture can be scalable. Through integration with the reinforced IDEA and variable-architecture encoding strategy, the design of the deep neural architecture can be adaptively scalable. Experiments and comparisons demonstrate the effectiveness and superiority of the proposed method.

The article titled "Task Allocation on Layered Multi-Agent Systems: When Evolutionary Many-Objective Optimization

Digital Object Identifier 10.1109/TEVC.2021.3096336

Meets Deep Q-Learning" by Li *et al.* constructed a novel layered multiagent system (MAS) model to address the multitask multiagent allocation problem, where the deep Q-learning method in the first layer is introduced to simplify the prioritization of the original task set, and the modified shift-based density estimation (MSDE) method in the second layer is put forward to improve the conventional strength Pareto EA 2 (SPEA2) in order to achieve many-objective optimization on task assignments. Then, an MSDE-SPEA2-based many-objective optimization method is proposed to simultaneously address the many objectives, such as task allocation, makespan, agent satisfaction, and resource utilization. As compared with existing allocation methods, the developed method exhibits an outstanding performance for simultaneous task assignment and task.

The article titled "Robust Multimodal Representation Learning With Evolutionary Adversarial Attention Networks" by Huang *et al.* proposes a new method for robust multimodal representation learning effective to model the deep correlation between different modalities, which combines the attention mechanism with adversarial networks through the evolutionary training process. Specifically, a two-branch visual–textual attention model is proposed to correlate visual and textual content for joint representation. Then, adversarial networks are employed to impose regularization upon the representation by matching its posterior distribution to the given priors.

Zhang *et al.* in their article "Convolutional Neural Networks-Based Lung Nodule Classification: A Surrogate-Assisted Evolutionary Algorithm for Hyperparameter Optimization" build a deep convolutional neural network (CNN) for lung nodule classification using multilevel CNNs, where multiscale features are extracted using CNNs of the same structure but different kernel sizes in convolutional layers. Then, a Gaussian surrogate model is built as a surrogate method for hyperparameter optimization in CNNs. The proposed method is named hyperparameter optimization with a surrogate-assisted evolutionary strategy. A nonstationary kernel that allows the surrogate model to adapt to functions whose smoothness varies with the spatial location of inputs. Extensive experiments illustrate the superiority of the proposed HOSUES for the hyperparameter optimization of deep neural networks (DNNs).

The article titled "Evolutionary Deep Fusion Method and Its Application in Chemical Structure Recognition" by Liang *et al.* uses different DNNs, such as ResNet and DenseNet, to extract features as multiview features and then develops a method named the evolutionary deep fusion method based on GAs to search for an optimal combination scheme of different basic fusion operators to fuse the multiview features. The proposed method is applied to chemical structure recognition tasks. The experimental results show that the proposed method achieves better performance than the manual design methods.

The article titled "A Survey on Evolutionary Construction of Deep Neural Networks" by Zhou *et al.* provides an insight into the automated DNNs construction process by formulating it into a multilevel multiobjective large-scale optimization problem with constraints, where the nonconvex, nondifferentiable, and black-box nature of this problem makes EAs to stand out as a promising solver. Then, the authors provide a systematical review of existing evolutionary DNN construction techniques from different aspects of this optimization problem and analyze the pros and cons of using EA-based methods in different optimization scenarios.

The article titled "Two-Stage Evolutionary Neural Architecture Search for Transfer Learning" by Wen *et al.* proposes a two-stage evolutionary neural architecture search (NAS) for transfer learning (EvoNAS-TL), which searches for an efficient subnetwork of source model for the target task, where the NAS is formulated as a multiobjective optimization problem that concurrently minimizes the prediction error and model size. The experimental results show that EvoNAS-TL effectively improves the classification error and reduces the model size in transfer learning.

The article titled "Adaptive Genetic Algorithm-Aided Neural Network With Channel State Information Tensor Decomposition for Indoor Localization" by Zhou *et al.* proposes to combine backpropagation neural network (BPNN) and adaptive GA (AGA) with channel state information tensor decomposition for indoor Wi-Fi fingerprint localization. Specifically, the tensor decomposition algorithm based on the parallel factor analysis model and the alternate least squares iterative algorithm is combined to reduce the interference of the environment. In order to find the global optimal solution of the nonlinear function, the AGA is introduced to optimize the BPNN, where the crossover probability and the mutation probability are dynamically adjusted according to the fitness to achieve a faster convergence rate and to avoid convergence in the case of the local optimal. Experimental results show that the proposed algorithm has high localization accuracy, while improving the data processing ability and fitting the nonlinear relationship.

In summary, the selected papers for this special issue highlight a subset of the challenging and novel applications when evolutionary computation meets deep learning. The Guest Editors would like to thank all the authors who submitted their work to the special issue, and all the reviewers for their hard work in completing timely and constructive reviews. Special thanks go to the former and current Editor-in-Chiefs, Prof. Kay Chen Tan, Prof. Carlos A. Coello Coello, and the members of the editorial team for their support during the editing process of this special issue. They worked closely with the Guest Editors to ensure the excellent quality of this issue and guarantee its success. To carry out this work, some of the Guest Editors are supported in part by the National Natural Science Foundation of China under Grant 61300167 and Grant 61976120; in part by the Natural Science Foundation of Jiangsu Province under Grant BK20191445; in part by the Qing Lan Project of Jiangsu Province; in part by the Marsden Fund of New Zealand Government under Contract VUW1913 and Contract VUW1914; in part by the Science for Technological Innovation Challenge Fund under Grant E3603/2903; in part by the University Research Fund at Victoria University of Wellington under Grant 223805/3986; in part by the MBIE Data Science SSIF Fund under Contract RTVU1914; and in part by the National Natural Science Foundation of China under Grant 61876169.

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