Guest Editorial
Special Issue on Structured Multi-Output Learning: Modeling, Algorithm, Theory, and Applications

STRUCTURED multioutput learning is a topic in artificial intelligence that considers multiple structured outputs prediction for a given input. The output may involve structured objects in the form of sequence, string, tree, lattice, or graph and has values that are characterized by diverse data types, such as binary, nominal, ordinal, and real-valued variables. Such learning problems arise in a variety of real-world applications, ranging from document classification, computer emulation, sensor network analysis, concept-based information retrieval, and human action/causal induction to video analysis, image annotation/retrieval, gene function prediction, and brain science. As many complex real-world scenarios can be posed as a structured multioutput learning problem, their importance and popularity have been increasing steadily.

Within the machine-learning community, for example, structured multioutput learning has transpired in the form of multilabel/multiclass classification, multitarget regression, multiconcept retrieval (i.e., retrieval problems with query and documents containing multiple concepts), hierarchical classification with class taxonomies, label sequence learning, sequence alignment learning, supervised grammar learning, and many others.

In this special issue, the state-of-the-art scientific works in addressing some of the greatest challenges of structured multioutput learning are sought. In our call for article, we welcome all original submissions that focus on modeling, algorithm, theory, real-world applications, and related literature reviews/surveys of structured multioutput learning.

A total of 37 articles on structured multioutput learning have been received, out of which 15 high-quality articles have been chosen and accepted for publication in this special issue. The contents of these 15 articles are briefly discussed in what follows.

In the practical implementations of non-Gaussian statistical models, it is infeasible to arrive at an analytically tractable solution for estimating the posterior distributions of the parameters. Recently, the extended variational inference (EVI) with a number of non-Gaussian statistical models was considered in the article by Z. Ma *et al.* for multioutput learning. In their work, two core approximation strategies, namely, multiple and single lower bound approximations have been studied as possible analytically tractable solutions to the variational objective function.

Multioutput Gaussian processes (MOGPs) are extensions of classical Gaussian processes (GPs) for predicting multiple-output variables (also called channels/tasks) simultaneously. By modeling cross-channel dependences through cross convolution in the spectral domain, the article by K. Chen *et al.* proposed a new multioutput convolution spectral mixture (MOCSM) kernel for MOGPs in multioutput learning. MOCSM obtains the desirable property and can be reduced to the well-known spectral mixture (SM) kernel when a single channel is considered. The results of extensive experiments demonstrate the advantages of the proposed kernel and its promising performance in multioutput learning.

The interpretability of recurrent neural networks (RNNs) is a topic that has been less explored. To understand the inner mechanism of RNNs, B. J. Hou and Z. H. Zhou find that finite-state automaton (FSA) that processes sequential data offers greater interpretable inner mechanism according to the definition of interpretability and can be learned from RNNs as the interpretable structure. They proposed methods to learn FSA from RNN based on two different clustering methods. Moreover, they analyzed how the number of gates affects the performance of RNN and observe that the FSA learned from RNN gives semantic aggregated states. This article contributes to the theoretical understandings of RNN for multioutput learning.

Multilabel classification can significantly benefit from feature selection methods for handling high-dimensional sparse data set. However, the increasing complexity of multilabel feature selection, especially on continuous features, requires novel ways to manage data effectively and efficiently in distributed computing environments. To address this issue, J. Gonzlez-Lopez *et al.* presented a distributed model for mutual information (MI) adaptation involving continuous features and multiple labels on Apache Spark.

To better learn the correlations among image features, as well as labels, C. Li *et al.* presented a novel deep metric learning method to explore a latent space, where images and labels are embedded via two unique deep neural networks, respectively. They propose a two-way deep distance metric over the embedding space from two different views, i.e., the

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distance between one image and its labels is not only smaller than those distances between the image and its labels' nearest neighbors but also smaller than the distances between the labels and other images corresponding to the labels' nearest neighbors. A new deep metric learning model for multioutput learning is proposed.

Label imbalance and noisy data that are commonly seen in the scenario of named entity recognition (NER) are largely neglected in the existing works. To address these two issues, J. Zhou *et al.* proposed a method termed robust sequence labeling (RoSeq) to handle the label imbalance issue by incorporating label statistics in the conditional random field (CRF) loss.

Large-scale multilabel learning (LMLL) assigns relevant labels for unseen data from a huge number of candidate labels. It is perceived that labels exhibit a long tail distribution in which a significant number of labels are tail labels. Most previous studies consider that the performance would benefit from incorporating tail labels. Nonetheless, it is not quantified how tail labels impact the performance. To address this issue, T. Wei and Y. Li showed that whatever labels are randomly missing or misclassified, the impact of labels on commonly used LMLL evaluation metrics (Propensity Score Precision (PSP)@k and Propensity Score nDCG (PSnDCG)@k) is directly related to the product of the label weights and label frequencies.

Network embedding is capable of providing low-dimensional feature representations for various machine-learning applications. H. Hong *et al.* taken advantage of network embedding in the view of multioutput learning. They proposed a generative adversarial network embedding (GANE) model to adapt the generative adversarial framework for better performance on multioutput problems.

Y. Zheng *et al.* developed a dynamically spatiotemporal regularization model for multioutput learning, which addresses the challenging boundary effects that exist in the correlation filter (CF)-based visual tracking.

Existing image subcategorization works relying on expert knowledge, and labeled images are both time-consuming and labor-intensive. To address these issues, Y. Yao *et al.* proposed to select and subsequently classify images into categories and subcategories. They first obtain a list of candidate subcategory labels from untagged corpora. Then, they purify these subcategory labels by calculating the relevance to the target category. This article proposed a novel approach to reduce the dependence on expert knowledge and labeled images in multioutput learning.

Zero-shot learning (ZSL), a type of structured multi-output learning, has attracted much attention due to its low requirement on training data in the target classes. Conventional ZSL methods usually project visual features into the semantic space and assign labels by finding their nearest prototypes. However, this type of nearest neighbor search (NNS)-based method often suffers from great performance degradation because of the nonuniform variances between different categories. H. Zhang *et al.* proposed a probabilistic framework by taking covariance into account to deal with the abovementioned issues.

Q. Li *et al.* proposed a caching strategy to replace the less frequently used kernel values in a novel SVM algorithm that adaptively achieves high hit ratios with little runtime overhead among different problems, including multilabel classification, multiclass classification, and multioutput regression problems.

Domain adaptation aims to exploit the supervision knowledge in a source domain for learning prediction models in a target domain. Z. Wang *et al.* proposed a novel representation learning-based domain adaptation method to transfer information from source to target domain where the labeled data are scarce in multioutput learning.

High-level semantic knowledge in addition to low-level visual cues is essentially crucial for cosaliency detection. Z. Zha *et al.* proposed a novel end-to-end deep learning approach for robust cosaliency detection by simultaneously learning high-level groupwise semantic representation as well as deep visual features of a given image group involving multioutput learning.

Last but not least, D. Xu *et al.* presented a survey to generalize different forms of multioutput learning in a single framework. It offers a comprehensive review and analysis of the multioutput learning paradigm. Some emerging challenges with multioutput learning from the perspective of the four Vs of Big data as potential research directions worthy of further studies have been delineated and discussed.

To summarize, the articles that appeared in this special issue reflect the state of the art in the fundamental research and development of multioutput learning and its applications to a wide range of relevant problems. Hence, the guest editors would like to thank all the authors for their utmost contributions in making this special issue a great success.

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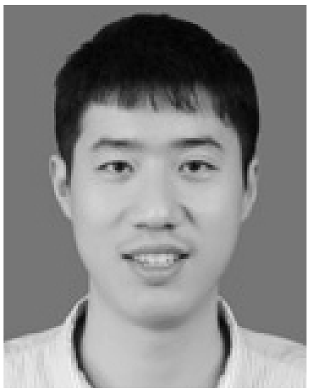

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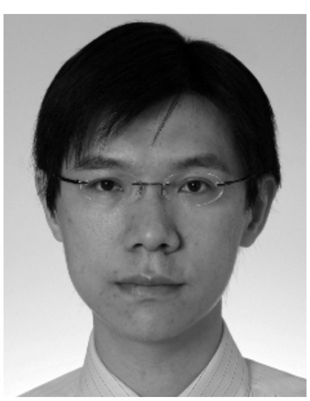

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