Seminar on Reservoir Computing and its Applications

Date and Time: July 18 (Thu), 2024, 15:00-18:00
Venue: Room 611B, 6th floor, Building 2, Nagoya Institute of Technology [MAP]
Organizer: Gouhei Tanaka (Dept. Computer Science, NITech)

Program

15:00-15:50 **Denis Kleyko** (Örebro University & Research Institutes of Sweden)

Title: On Interplay Between Reservoir Computing & Hyperdimensional Computing

Abstract: Both reservoir computing and hyperdimensional computing rely on the idea of computing with randomized distributed representations. Over the years, we have seen how the two could interplay in various ways and I will present some of these observations in the talk. The talk will include three related narratives (if time allows). We will begin by first introducing how the ideas used for analyzing the memory capacity of distributed representations lead to understanding the mechanisms affecting the capacity of reservoir computing models. Second, the capacity analysis involves making parallels between the two frameworks, which in turn, allows leveraging the ideas from hyperdimensional computing models that use integer-valued representations (e.g., multiply-add-permute model) to design minimalistic echo state networks amenable to realization in digital hardware (e.g., field programmable gate arrays). Third, there is a recent proposal for reservoir computing ("next generation reservoir computing") that suggests that the reservoir should be formed using localist representations as an explicit concatenation of the memory buffer with some time-delayed states and the corresponding higher-order interactions of the states in the buffer. We demonstrate that this proposal could be first interpreted as a polynomial kernel machine that in turn could be approximated with randomized compositional distributed representations using the ideas of self-binding from hyperdimensional computing. Our proposal: a) brings the idea of higher-order interactions into the design space of reservoir computing models operating with randomized representations; b) provides computational savings (in terms of the reservoir size); and c) has an elegant realization via a circuit that is based on Sigma-Pi neurons that can iteratively compute distributed representations of higher-order interactions for an arbitrary order. A proof-of-concept of the proposed approach has been implemented on a neuromorphic chip Loihi 2.

16:00-16:50 **Ziqiang Li** (The University of Tokyo)

Title: Multiple-Reservoir Echo State Network: A Promising Reservoir Computing-based Model for Processing Time Series Tasks in Edge Computing Scenarios

Abstract: Edge computing is a new computing paradigm that aims to address the limitations of traditional cloud computing in handling data generated by an increasing number of Internet of Things (IoT) devices connected to the Internet. The concept of Edge Machine

Learning (Edge ML) strives to facilitate the training and deployment of ML models directly on edge devices, encompassing both Edge Learning (EL) and Edge Inference (EI). At present, edge inference has been widely applied by means of developed edge devices. However, Edge Learning (EL, i.e., training on edge devices) is still a promising paradigm since it requires local model training with constrained computational resources and limited training data. Reservoir Computing (RC) is a promising solution for dealing with time-series machine learning tasks on edge. In this talk, an RC-based framework named multiple-reservoir echo state network (MRESN) has become more and more popular because of its high effectiveness and efficiency. Based on this background, an emerging problem is to improve the computational ability of MRESN. I will present my recent work on optimizing MRESN from the perspective of searching for a suitable topology corresponding to a given time-series task. In this work, a unified approach is proposed to represent the topology of MRESN. Moreover, a genetic algorithm-based method is proposed to automatically search for an appropriate network topology. Lastly, the experimental results will indicate that topology is an important factor that affects computational ability.

17:00-17:50 **Hiroto Tamura** (The University of Tokyo)

Title: Temporal Information Processing Using Mahalanobis Distance of Reservoir States (MD-RS)

Abstract:

Reservoir computing is increasingly recognized as an efficient machine learning method for time-series processing, notable for its low learning cost and reduced training data requirements. Departing from the conventional linear regression readout used in standard reservoir computing, this study introduces a "distance-based readout" method. This method is especially effective for tasks requiring differentiation, such as anomaly detection and classification.

First, we introduce the Mahalanobis Distance of Reservoir States (MD-RS) for online time-series anomaly detection. In the MD-RS method, the reservoir's responses to normal time series are fitted to a multivariate Gaussian distribution. During testing, the Mahalanobis distance from this fitted distribution is used as a measure of anomaly. We conducted a comprehensive performance evaluation using the UCR Anomaly Archive to compare the state-of-the-art methods with our MD-RS approach.

Further, we extend MD-RS for time series classification. In this method, the reservoir's responses to each class are fitted to a multivariate Gaussian distribution, and classification is based on the distance (measured as Kullback–Leibler divergence) between the distribution of each class and that of the response during testing. We evaluated the performance of the proposed readout and standard readouts using linear regression or support vector machines, using four time-series classification benchmarks. Our proposed method demonstrates superior performance compared to existing methods.