Reservoir computing with applications to time series forecasting

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Abstract

Many dynamical problems in engineering (including financial), control theory, signal processing, time series analysis and forecasting, and supervised dynamic machine learning can be described using input/output (IO) systems. State-space systems are known to provide a parsimonious and computationally efficient way to model the relation between time evolving explanatory variables (the input) and a collection of dependent or explained variables of interest (the output). Whenever a true functional IO relation cannot be derived from first principles, it can proved that some families of state-space systems (under mild conditions) serve as universal approximants. We shall show that particular families of such state-space systems, the so-called Reservoir Computing (RC) systems, with extremely simple and easy to implement architectures, enjoy universal approximation properties which have been proved in different setups. The defining feature of RC systems is the fact that one of their components (usually the state map) are *randomly generated* and the observation equation has an easily tractable form. From the machine learning perspective, RC systems can be seen as recurrent neural networks with *randomly generated* and non-trainable weights and *a simple-to-train readout* layer (often a linear map). Results will be presented in a discrete-time setup. We will make a general introduction into up to date theoretical developments, will discuss connections with research contributions in other fields, and will address details of particular applications of RC systems to time series forecasting.

Tentative structure

Session I. Introduction
Concept of Reservoir Computing, main contributions in the field, links to models in dynamic supervised machine learning. Examples of successful applications.

Session II. State-space systems, filters, functionals, and their properties. Reservoir computing families as universal approximates of fading memory filters
Essential notation, definitions, properties. Examples of reservoir systems: Echo-State Networks, State-Affine Systems, Deep Reservoir Networks.
Link to classic universal approximation results for feed-forward networks. Selection of the RC universality results in different setups. Error decomposition and the need for approximation and generalisation error bounds in the statistical learning context.

Session III. Application of reservoir systems to time series forecasting
Time series forecasting exercises with reservoir computing. Short- and long-term forecasting of realized volatility time series.