



Modeling Time-Series with Deep Networks

av

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# Abstract

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Deep learning is a relatively new field that has shown promise in a number of applications and is currently outperforming other algorithms on a variety of commonly used benchmark data sets. One attractive property of deep learning methods is that they take advantage of unlabeled data, which is plentiful and cheaper to obtain than labeled data, in order to construct its own features which reduces the need for heavy pre-processing of the data. However, much focus has been on applications and methods for static data and not so much on time-series data.

Learning models of complex high-dimensional time-series data introduces a number of challenges that either require modifications to the learning algorithms or special pre-processing of the data. Some of the signals in multivariate time-series data are often redundant since they come from sensors with different properties or spatial locations but measure the same real-world phenomenon. Furthermore, sensors are subject to errors in the measurements due to faults, noise, and sensor bias. Therefore, a common approach to analysing multivariate time-series data is to heavily pre-process the data to reduce the noise and complexity with noise-reduction techniques, feature extraction and signal removal. However, many of these steps require expertise of the domain which is difficult and expensive to acquire, or could even be non-existent. The primary contribution of this thesis is the algorithmic modifications to a deep learning algorithm that enables the algorithm to better handle multivariate time-series data. The aim is to change the amount of impact each input signal has on the feature learning. This reduces the influence that noisy or task-irrelevant inputs have on the learned features.

The secondary contribution of this thesis is the investigation of the feasibility to construct features from unlabeled raw time-series data. An advantage of using deep networks is the promise of unsupervised feature learning that removes the need to manually hand-design features. However, many of the reported successful applications that uses deep learning, and especially those applied to time-series data, still have used some form of feature extraction as a pre-processing step. This thesis investigates the importance of feature extraction for time-series data by comparing the performance from a deep network trained on raw data with models trained on feature transformed data.

A final contribution of this thesis is the application of deep learning methods to new data sets that can follow the success deep learning methods has had in computer vision applications. This thesis takes the first step by using new, challenging, and interesting multivariate time-series data sets and suggests that they can be used as benchmark data sets in order to further develop deep learning algorithms specific for multivariate time-series data.

*Keywords:* multivariate time-series, deep learning, representation learning, unsupervised feature learning, selective attention, weighted cost function, electronic nose, automatic sleep stage classification

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