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Causal Orthogonal Functions: A Causal Inference approach to temporal feature extraction

Nicolas-Domenic Reiter[1], Jakob Runge[1,2], and Andreas Gerhardus[1]
[1]Deutsches Zentrum für Luft- und Raumfahrt e.V., Institute of Data Science , 07745 Jena, Germany
[2]Technische Universität Berlin 10623 Berlin, Germany

Understanding complex dynamical systems is a major challenge in many scientific disciplines. There are two aspects which are of particular interest when analyzing complex dynamical systems: 1) the temporal patterns along which they evolve and 2) the governing causal mechanisms.

Temporal patterns in a time-series can be extracted and analyzed through a variety of time-series representations, that is a collection of filters. Discrete Wavelet and Fourier Transforms are prominent examples and have been widely applied to investigate the temporal structure of dynamical systems.

Causal Inference is a framework formalizing questions of cause and effect. In this work we propose an elementary and systematic approach to combine time-series representations with Causal Inference. Hereby we introduce a notion of cause and effect with respect to a pair of arbitrary time-series filters. Using a Singular Value Decomposition we derive an alternative representation of how one process drives another over a specified time-period. We call the building blocks of this representation Causal Orthogonal Functions. Combining the notion of Causal Orthogonal Functions with a Wavelet or Fourier decomposition of a time-series yields time-scale specific Causal Orthogonal Functions. As a result we obtain a time-scale specific representation of the causal influence one process has on another over some fixed time-period. This allows to conduct causal effect analysis in discrete-time stochastic dynamical systems at multiple time-scales. We illustrate our approach by examining linear VAR processes.