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Time-varying correlation structure estimation and local-feature detection for spatio-temporal data

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Abstract

Spatial-temporal data arise frequently in biomedical, environmental, political and social science studies. Capturing dynamic changes of time-varying correlation structure is scientifically important in spatio-temporal data analysis. We approximate the time-varying empirical estimator of the spatial correlation matrix by groups of selected basis matrices representing substructures of the correlation matrix. After projecting the correlation structure matrix onto a space spanned by basis matrices, we also incorporate varying-coefficient model selection and estimation for signals associated with relevant basis matrices. The unique feature of the proposed method is that signals at local regions corresponding with time can be identified through the proposed penalized objective function. Theoretically, we show model selection consistency and the oracle property in detecting local signals for the varying-coefficient estimators. The proposed method is illustrated through simulation studies and brain fMRI data.

Keywords: fMRI, Local feature, Longitudinal data, Penalty, Varying-coefficient model

1. Introduction

Modeling covariance structure is important for detecting associations among genes, spatial locations, social networks and brain connectivities. Developing sound spatio-temporal modeling and estimation is critical for capturing dynamic changes of associations. However, it is difficult to build a model for correlation structure for incorporating dynamic association changes that is flexible enough to capture time-varying structures, yet not burdened by high-dimensional parameter estimation. In addition, modeling spatial and temporal variations simultaneously tends to be more challenging than modeling each of them separately. Further, it is theoretically and computationally challenging to provide statistical inference for detecting dynamic changes in correlation structure.

This paper is motivated by fMRI data arising from research on children's attention deficit hyperactivity disorder (ADHD). We are interested in identifying associations and changes of associations over time among responses of brain activities from different regions in the brain. In particular, correlation structures corresponding to the regions of interest (ROIs) in the brain can change over time, although the process may be stationary, or nearly stationary. To extract the underlying signal changes of association over time, we propose a time-varying correlation structure model where dynamic changes of associations are modeled as a varying-coefficient model.

The related literature on local signal detection includes the fused LASSO in Tibshirani et al. [32], and the adaptive bandwidth selection approach in Miller and Hall [24] under the framework of local polynomial regression. However, as the dimension of variables increases, the aforementioned methods have computational limitations and are not effective for detecting local patterns. In addition, a functional linear regression model is proposed by James et al. [13] and Zhou et al. [41] to detect zero sub-regions. In contrast to functional data and kernel approaches, we propose a group

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