

Functional Structural Equation Model

How can directional relationships among multivariate functional data be estimated, and what method can effectively identify these in high-dimensional nonlinear settings?

This article by Kuang-Yao Lee and Lexin Li (UC Berkeley), published in the Journal of the Royal Statistical Society, introduces a functional structural equation model (SEM) for estimating directional relations from multivariate functional data. Unlike traditional SEMs focusing on fixed-dimensional variables, this model handles random functions over time, applicable in brain connectivity analysis and similar fields.

The authors propose a two-step process: first, determining directional order among functions using a novel operator-level score function; second, applying sparse functional additive regression to capture nonlinear, additive relationships between functional predictors and responses. They develop a functional regression operator to generalize regression coefficients to this functional context.

The model addresses high dimensionality and nonlinearity by using dimension reduction via Karhunen–Loève expansions and pre-neighborhood selection to reduce computation. Theoretical results establish consistency of order determination, sparse regression, and directed acyclic graph estimation as function and sample sizes grow.

Simulations show superior performance compared to alternatives adapted from multivariate methods. An application to brain effective connectivity using ECoG data illustrates practical utility, revealing differences in connectivity patterns related to decision-making under risk.

This work extends SEM methodology to complex, functional data scenarios, offering a scalable, theoretically grounded approach to uncover causal structures in neuroscience and other domains with multivariate functional observations.

MAJOR TAKEAWAYS:

- Functional SEM extends classic SEM to random functions with nonlinear, additive relations.
- Novel score function and sparse regression enable accurate directional order and relation estimation.
- Method outperforms alternatives and successfully applied to brain connectivity analysis.

WHO NEEDS TO KNOW:

- Data Scientists
- Neuroscientists
- Academics

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