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Structured Tensor Models for High-Dimensional Inference: Theory and Algorithms with Applications to Neuroimaging



Prof. Waheed U. Bajwa

Rutgers University | New Brunswick, USA



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Abstract

Recent decades have witnessed rapid advances in sensing and imaging technologies, enabling the collection of increasingly complex and high-dimensional data. This has fueled growing interest in high-dimensional inference, where the number of data samples is often much smaller than the number of raw features per sample. Such inference problems are inherently ill-posed because of the overwhelming number of unknown parameters. Regularization plays a central role in addressing this challenge; common strategies include sparsity for vector-valued data and low-rank assumptions for matrices. Modern datasets, however, are often intrinsically multidimensional, including color images, videos, depth images, and various types of MRI scans, and are naturally represented as higher-order arrays, or tensors. Moreover, multimodal data fusion frequently produces data in tensor form. Reshaping these tensors into vectors or matrices can destroy the underlying correlation structure and further exacerbate the dimensionality problem. In this talk, we present our recent work on leveraging structured tensor decompositions as natural regularizers for high-dimensional inference from multidimensional data. We focus on two related settings: generalized linear models, including logistic regression, and ridge regression with matrix- and tensor-valued covariates. Our central modeling device is the Low Separation Rank (LSR) decomposition, which provides a principled way to control model complexity while retaining multidimensional structure. For generalized linear models, we discuss estimation algorithms and summarize our main theoretical results for models with LSR structure. For ridge regression, we discuss computational approaches that impose or promote LSR structure while balancing data fit and model complexity. We then turn to neuroimaging applications using resting-state functional magnetic resonance imaging data from the Human Connectome Project, where functional connectivity matrices are used to predict cognition-related behavioral measures. These results illustrate how structured tensor models can reduce the burden of estimation while preserving scientifically meaningful organization in neuroimaging data.

Bio

Waheed U. Bajwa (IEEE Fellow, Class of 2025) is a professor in the Department of Electrical and Computer Engineering at Rutgers University-New Brunswick and a member of the graduate faculty of the Department of Statistics. He received his Ph.D. in electrical engineering from the University of Wisconsin-Madison in 2009. Before joining Rutgers in 2011, he was a postdoctoral research associate at Princeton University and a research scientist at Duke University. He later returned to Princeton as a visiting fellow in the Center for Statistics and Machine Learning from 2021 to 2022. His research interests include statistical signal processing, high-dimensional statistics, machine learning, inverse problems, and networked systems. Dr. Bajwa has received several research and teaching awards, including the Army Research Office Young Investigator Award, the National Science Foundation CAREER Award, the Rutgers Presidential Outstanding Faculty Scholar Award, and the Rutgers Warren I. Susman Award for Excellence in Teaching. He has held numerous editorial and leadership roles within the IEEE Signal Processing Society. He currently serves as a Senior Editorial Board Member of IEEE Signal Processing Magazine and an Associate Editor of IEEE Transactions on Information Theory, and he is the Past Chair of the Society's Signal Processing for Communications and Networking Technical Committee.

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