INTERNATIONAL CONGRESS ON Differential Geometry AND RELATED TOPICS

August 17–18, 2026
Ege University, İzmir, Türkiye

Beyond Sparsity: Post-Shrinkage Estimation and Prediction in High-Dimensional Probability Models with Weak Signals

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Abstract. In many contemporary high-dimensional applications, the underlying signal structure is often more complex than the classical sparsity paradigm suggests. While only a small subset of predictors may exhibit strong effects, a large number of variables frequently contribute weak but collectively important signals. Standard penalized estimation and variable selection procedures are effective in identifying dominant predictors; however, they often overlook weak signals, leading to suboptimal estimation and prediction performance.

In this talk, we develop a post-shrinkage framework for high-dimensional regression models that explicitly accounts for the presence of weak signals. The proposed methodology combines the strengths of sparse model selection with post-selection adjustment, yielding improved prediction accuracy and enhanced estimation efficiency. We establish the theoretical properties of the proposed estimators through asymptotic analysis and characterize their behavior under both sparse and weakly sparse signal regimes.

Theoretical expressions for bias and risk are established and critically assessed under a range of high-dimensional settings.. Extensive simulation studies demonstrate that the proposed post-shrinkage strategy consistently outperforms conventional penalized estimators and several state-of-the-art machine learning approaches across a broad range of high-dimensional settings. Applications to real high-dimensional datasets further illustrate the practical advantages of the method and highlight the importance of incorporating weak signals beyond traditional variable selection frameworks.

The talk concludes with a discussion of several open problems at the intersection of high-dimensional statistics, predictive modeling, and weak-signal learning, together with preliminary results that suggest promising directions for future research.

References

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