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Physics-Informed Statistical Learning for Data-Driven Decision Making in Science and Industry

The increasing availability and complexity of data are transforming decision-making processes across science, industry, and engineering. Modern datasets are often high-dimensional, heterogeneous, and structured over space and time, and are collected on domains with complex geometries, including environmental domains, biological structures, and engineering systems. In many applications, the underlying phenomena are governed by known physical mechanisms, while multiple data sources provide complementary information. In other cases, such as pharmacokinetics, data may be limited, making robust inference challenging without integrating prior knowledge. In these settings, standard statistical approaches may fail to fully exploit available information.

This lecture presents a class of physics-informed statistical learning methods that integrate data with physical knowledge to support more reliable inference and decision-making. These approaches extend nonparametric regression and classical statistical learning models by incorporating regularization based on differential operators, including problem-specific partial differential equations. The resulting framework enables the analysis of spatial, spatio-temporal, and functional data over complex domains, and provides a natural approach to kinetic modeling in industrial applications.

By combining statistical rigor with physically grounded modeling, these methods improve interpretability, enhance predictive accuracy, and support the integration of heterogeneous data sources. Their practical value will be highlighted by illustrative applications from environmental monitoring, engineering design, and medical and pharmaceutical research, including stability studies and emerging measurement technologies such as spatial transcriptomics. The lecture concludes by outlining key challenges and future directions, emphasizing the role of physics-informed statistical learning as a unifying framework for advancing data-driven decision-making and scientific discovery.

Special/ Invited session

Classification

Both methodology and application

Keywords

hihg-dimensional and complex data; nonparametric regression

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