ME Seminar

Advancing Computational Mechanics through Scientific Machine Learning for Differential Eigenvalue Problems

Smriti, Institute Postdoctoral Fellow, Department of Mechanical Engineering, Indian Institute of Technology, Madras

ABSTRACT

Computational mechanics has traditionally relied on numerical methods that are built around the mathematical structure of the governing physical problem. As engineering simulations move toward repeated analysis, design exploration, inverse problems, and increasingly complex physical systems, there is growing interest in scientific machine learning as a complementary computational paradigm. An important question, however, is how learning-based methods can achieve computational efficiency without sacrificing the physical consistency, numerical accuracy, and reliability expected from established computational mechanics techniques. In this talk, I will discuss a structure-preserving approach to physics-informed learning in which known mathematical and physical properties are incorporated directly into the approximation space and resulting algebraic formulation. The main focus will be Eig-PIELM, a mesh-free framework for differential eigenvalue problems based on Physics-Informed Extreme Learning Machines (PIELMs). Standard PIELM retains the simplicity of a fixed-feature, single-hidden-layer representation whose output coefficients can be determined without iterative backpropagation. For eigenvalue problems, however, the simultaneous presence of the unknown eigenvalue and eigenfunction introduces a nonlinear coupling that destroys this conventional one-shot linear structure. Eig-PIELM addresses this difficulty through two complementary ideas. Boundary conditions are first imposed exactly by projecting the approximation onto the null space of the discrete boundary operator. The resulting boundary-admissible formulation is then exploited together with the underlying self-adjoint structure to recast the coupled problem as a symmetric generalized eigenvalue problem. Multiple eigenvalues and their corresponding eigenfunctions can consequently be obtained through a single direct spectral solve, without penalty-based boundary enforcement or iterative neural-network training. The talk will discuss how ideas from computational mechanics and machine learning can be combined to develop efficient and physically consistent learning-based solvers, and how these ideas may be extended toward reusable, nonlinear, and coupled computational models.

ABOUT THE SPEAKER

Dr. Smriti is an Institute Postdoctoral Fellow in the Department of Mechanical Engineering at IIT Madras. She received her Ph.D. in Applied Mechanics from IIT Delhi and subsequently worked as a postdoctoral scholar in the Mechanics and Materials Unit at the Okinawa Institute of Science and Technology, Japan. Her research background spans theoretical and computational mechanics, including multiscale modelling of nanostructures, nonlinear and elastoplastic Cosserat rods, finite-element and related computational formulations, damage and phase-field modelling, and adaptive computational methods. Her research trajectory from applied mechanics to physics-informed machine learning is also reflected in the research-background section of the talk. Her current research focuses on developing physics-informed learning methods for computational mechanics, with particular emphasis on incorporating physical constraints and mathematical structure directly into learning-based numerical formulations. She has developed and extended Physics-Informed Extreme Learning Machine approaches for differential eigenvalue problems, interface problems, plate models, and coupled physical systems. Her broader research interests lie at the intersection of computational mechanics, numerical methods, and scientific machine learning, with the goal of developing accurate, efficient, interpretable, and reliable computational tools for engineering analysis.

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