

STRUCTURE-PRESERVING AND HIGH-FIDELITY SPECTRAL/HIGH-ORDER METHODS IN THE ERA OF AI4S

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ABSTRACT

Spectral, spectral element, and hp finite element methods are central high-order tools for high-fidelity scientific computing. Their high accuracy, tensor-product structure, locality, and high computation-to-memory ratio make them well suited for modern heterogeneous and exascale architectures. Beyond accuracy, however, reliable simulations of complex physical systems require the preservation of intrinsic structures such as conservation laws, divergence constraints, positivity, entropy dissipation, symplecticity, and energy stability.

The rise of AI for Science offers new opportunities to accelerate and augment high-order methods through neural operators, physics-informed learning, learned solvers, data-driven closures, and AI-assisted adaptivity. Yet robustness, physical consistency, and long-time stability remain major challenges for purely data-driven models. This minisymposium focuses on structure-preserving and high-fidelity spectral/high-order methods in the era of AI4S, emphasizing rigorous numerical foundations, efficient HPC implementations, and principled integration with machine learning.

Topics include conservative, divergence-free, positivity-preserving, entropy-stable and energy-stable schemes; asymptotic-preserving and symplectic methods; fast solvers, preconditioners, and GPU-oriented implementations; spectral or polynomial-basis neural operators; variational and physics-informed learning; learned hp-adaptivity;

AI-assisted preconditioning; and structure-preserving neural closures, with applications in fluids, electromagnetics, kinetic equations, waves, materials, geophysical flows, and multiphysics simulations.

SPEAKERS

1. Sheng Chen (Beijing Normal University): A tensor-train tensor neural network Galerkin method for high-order approximation
2. Huiyuan Li (Institute of Software Chinese Academy of Sciences): Bridging spectral element methods and heterogeneous exascale systems: Practice on China's indigenous supercomputing platforms
3. Lu Lu (Yale University): NOEM: efficient and scalable finite element method enabled by reusable neural operators
4. Zhiping Mao (Eastern Institute of Technology, Ningbo): Solving high-dimensional PDEs using neural networks with error control models
5. Changtao Sheng (Shanghai University of Finance and Economics): Liberating spectral accuracy: spectral Monte Carlo methods for high-dimensional PDEs
6. Lunji Song (Lanzhou University): Explicit construction of approximate Kolmogorov superpositions with C^2 -smoothness
7. Bo Wang (Hunan Normal University): High-order boundary integral method for solving multiple scattering problem in layered media
8. Wei Wang (Academy of Mathematics and Systems Science, Chinese Academy of Sciences): p-robust eigensolvers and applications to localized states
9. Fanhai Zeng (South China University of Technology): Bi-orthogonal fPINN: A physics-informed neural network method for solving time-dependent stochastic fractional PDEs
10. Jun Zhang (Guizhou University of Finance and Economics): Efficient numerical algorithms for variable-density and variable-viscosity fluid-coupled phase-field
11. Tao Zhou (Academy of Mathematics and Systems Science, Chinese Academy of Sciences): Overcoming spectral bias with adaptive neural representation
12. Xiaolong Zhang (Hunan Normal University): Numerical investigation of the Schrödinger equations with low-regularity nonlinearities