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Leveraging physics-informed AI computing for simulating the transport of fusion plasmas

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For decades, plasma transport simulations in tokamaks have employed the finite difference method (FDM) to solve the transport equations, a coupled set of time-dependent partial differential equations. In this conventional approach, a significant number of time steps, typically over $O(10^5)$, are needed for a single discharge to prevent numerical instabilities induced by stiff transport coefficients. This results in significant computing time as costly transport models are repeatedly called in a serial manner, proportional to the number of time steps. Additionally, the unidirectional calculation inherent in FDM presents challenges for predicting regions prior to the initial condition or for applying additional temporal constraints.

In this work, we introduce a novel solution scheme for plasma transport simulation, using physics-informed neural networks (PINNs). Instead of adopting the traditional chronological computations of FDM, this new technique iteratively refines a function mapping spatiotemporal coordinates to plasma states, gradually minimizing errors in transport equations. The required number of iterative updates in PINNs is several orders of magnitude less than the chronological iterations in traditional FDM, and this approach is free from numerical instabilities arising from discretization on finite grids. Furthermore, the flexibility of PINNs enables more versatile "semi-predictive" simulations, permitting the application of arbitrary spatiotemporal constraints, such as sparse and finite conditions or intermediate temporal constraints, which more preserve the diagnostic fidelities. In this presentation, we discuss the features and potentials of our newly proposed PINN-based tokamak transport solver.

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