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Modelling dynamical systems: Learning ODEs with no internal ODE resolution

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Accurately modeling and simulating dynamic systems remains a central challenge in computational physics and numerical engineering. Traditional approaches, such as time series prediction and ordinary differential equation (ODE) modeling, have been widely explored in the literature. However, these methods fall short when applied to the complex and potentially discontinuous behavior of particle accelerator beams.
To address this challenge, we introduce a novel method called Inode, which leverages integral operators to handle discontinuities in beam dynamics. Inode reformulates the problem as a classical regression task, where pre-processed data defines the system behavior. The overall model is then cast as the solution to an ODE, while the regression component allows the computationally intensive ODE resolution to be removed from the training process.
We provide a formal analysis demonstrating Inode's consistency and convergence under reasonable assumptions. Experimental results further validate the method's robustness across both standard dynamic systems and particle accelerator data, showing significant advantages in computational efficiency and modeling flexibility.
This approach opens new avenues for accurate, scalable modeling of particle accelerator beams, addressing key limitations in existing techniques.

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