A Physics-Informed Fourier Neural Operator for Rapid Emulation of Dynamic Earthquake Rupture and Seismic Wave Propagation

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Abstract

This work explores a physics-informed operator learning approach for accelerating dynamic earthquake rupture simulations and seismic wave propagation. While high-fidelity models provide detailed insight into fault dynamics and wave physics, their computational cost remains a major barrier for large-scale applications such as inversion and uncertainty quantification.

As a first step, we establish a proof of concept in a one-dimensional (1D) dynamic rupture setting, where a stable high-order solver is used to generate training data across a parameterized frictional fault model. A Fourier Neural Operator (FNO) is trained to map a small set of physical parameters to full space-time solutions. The model demonstrates strong accuracy and significant potential for accelerating repeated evaluations.

This framework is designed to scale. Future work extends the approach to physics-informed training and higher-dimensional settings, progressing from 2D to full 3D rupture simulations using WaveQLab3D. The ultimate aim is to approximate complex rupture physics, including anelastic effects, advanced friction laws, perfectly matched layers (PML), and realistic boundary conditions, with fast and reliable surrogate models.

Keywords: Fourier neural operator, physics-informed neural operator, dynamic earthquake rupture, seismic wave propagation, WaveQLab3D, scientific machine learning