Learning Stochastic Predator–Prey Dynamics: Spectral Solvers and Neural Operator Surrogates

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Abstract

We study a stochastic predator–prey reaction–diffusion system with multiplicative Brownian fluctuations and Lévy jump disturbances. A Chebyshev spectral collocation scheme with Neumann boundary conditions is developed to simulate the system efficiently and accurately. The resulting high-fidelity data are used to train neural operator surrogates—specifically the Fourier Neural Operator (FNO) and DeepONet architectures—to approximate the mapping from initial conditions and stochastic inputs to spatio-temporal population fields. The learned models replicate the numerical solutions with high accuracy and enable rapid uncertainty quantification across large ensembles. Extinction probabilities estimated from these simulations provide insight into ecological risk under variable environmental conditions.

Keywords: SPDE, predator–prey model, Lévy noise, Chebyshev spectral method, neural operator, FNO, DeepONet, uncertainty quantification.