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PAPER

Machine learning stochastic differential equations for the evolution of order parameters of classical many-body systems in and out of equilibrium

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Abstract

We develop a machine learning algorithm to infer the emergent stochastic equation governing the evolution of an order parameter of a many-body system. We train our neural network to independently learn the directed force acting on the order parameter as well as an effective diffusive noise. We illustrate our approach using the classical Ising model endowed with Glauber dynamics, and the contact process as test cases. For both models, which represent paradigmatic equilibrium and nonequilibrium scenarios, the directed force and noise can be efficiently inferred. The directed force term of the Ising model allows us to reconstruct an effective potential for the order parameter which develops the characteristic double-well shape below the critical temperature. Despite its genuine nonequilibrium nature, such an effective potential can also be obtained for the contact process and its shape signals a phase transition into an absorbing state. Also, in contrast to the equilibrium Ising model, the presence of an absorbing state renders the noise term dependent on the value of the order parameter itself.

1. Introduction

Stochastic processes are fundamentally important in physics [1–3]. For instance, random microscopic fluctuations can strongly impact the evolution of macroscopic physical observables, e.g. order parameters close to phase transitions. Monte Carlo methods [4–6] are often the ‘benchmark’ for the computational treatment of classical many-body dynamics, allowing for efficient sampling of stochastic microscopic configurations and trajectories. The large-scale dynamics of the order parameter are instead typically modeled by a stochastic differential equation. The latter contains both a force term, leading to a deterministic drift, and a noise term yielding diffusive behavior[†]. [7, 8] However, establishing a connection between fluctuating microscopic stochastic trajectories and the coarse-grained evolution of the order parameter is a challenging task that can rarely be accomplished analytically.

[†] The drift and the diffusion represent the most basic ingredients for a coarse-grained dynamics. More general forms might include memory kernels or other non-Markovian time dependencies [7, 8].

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