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Governing equation construction for critical transitions in Langevin type NeuralSDEs

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Abstract: An appealing property of Langevin stochastic differential equations (SDEs) is their ability to model critical transitions between locally confined states (meta-stable states). Further, the analysis of such transitions is valuable to many scientific and industrial applications, such as the estimation of system failure rates or stock market crashes. Expanding upon recent developments in machine learning for dynamical systems, we propose an analysis methodology for learned SDE models, such as those where the energy function is described by a neural network, in which we construct a meaningful description of the emerging critical transition dynamics.

Our approach starts by identifying the meta-stable states as the basins of attraction in the learned SDE; these are given by level-sets of the potential function. From the heights of the potential barriers separating each pair of basins, we can estimate the mean first passage times between the corresponding meta-stable states. Finally, we approximate the critical transition dynamics in the long-time limit as a discrete Markov jump process between the identified meta-stable states. These dynamics are characterized by a governing equation (the forward Kolmogorov equation) in which the transition rates are calculated from the mean first passage times. Equations of this form can then be solved exactly and meaningful information about the long-term dynamics of the system extracted via expectations.

Keywords: Langevin dynamics, critical transitions, SDE learning