Simulation of non-Markovian dynamics by certified auxiliary models

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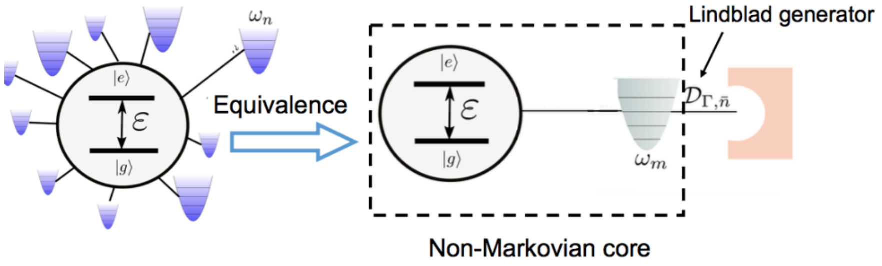
Abstract

We characterize the conditions which allow us to describe the general, non-Markovian dynamics of an open quantum system by means of a simpler model, consisting in an enlarged set of degrees of freedom undergoing a Markovian (Lindbladian) dynamics. After presenting the equivalence theorem between the two systems, we show how to exploit it to build up in a systematic and certified way auxiliary models, which can be treated efficiently by means of existing numerical techniques.

The understanding of the interaction of a quantum system with the surrounding environment is of crucial importance for modern physics, both from a theoretical and from a practical point of view. One of the main obstacles towards a fully satisfactory description of the dynamics of open quantum systems is certainly represented by the characterization of non-Markovian dynamics, where the presence of memory effects enhances considerably the complexity of the treatment, both with analytical and numerical techniques [1]. Here, we present a general approach to non-Markovian dynamics, which consists in dividing the influence of the environment on the open system into a non-Markovian core, which encloses all the memory effects during the evolution, and a further Markovian component, representing the unidirectional leakage of information out of the non-Markovian core [see the figure below for an illustration]. First, we report an equivalence theorem [2] which proves that a Gaussian bosonic environment evolving unitarily can be replaced by a Gaussian bosonic environment undergoing a Lindblad dynamics, if the first moments and the two-time correlation functions of the original and the auxiliary baths are the same at all times. Noticeably, as a special case, we recover the well-known pseudomodes approach [3], directly extending it to a different form of the coupling. Relying on this result, one can then develop [4] a systematic procedure to formulate auxiliary models consisting of few bosonic degrees of freedom, typically a network of interacting harmonic oscillators, in this way reducing dramatically the complexity of the environment. On the one hand, this allows for the evaluation of general, possibly highly non-Markovian evolutions of the original open system by applying efficiently standard numerical techniques, such as Monte Carlo wave Function methods, to simpler Lindbladian open-system dynamics. On the other hand, it also sets the ground for the systematic design of quantum simulators which reproduce in a certified way the dynamics of quantum systems subject to complex environments, as shown for a simple case study via an ion-trap simulator in [5].



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