Exponential Quantum Advantage for Simulating Open Systems

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A recent promising arena for quantum advantage is simulating exponentially large classical systems [1]. Here, we broaden this arena to include open classical systems experiencing dissipation. This is a particularly interesting class of systems since dissipation plays a key role in contexts ranging from fluid dynamics to thermalization. We adopt the Caldeira-Leggett Hamiltonian, a generic model for dissipation in which the system is coupled to a bath of harmonic oscillators with a large number of degrees of freedom. To date, the most efficient classical algorithms for simulating such systems have a polynomial dependence on the size of the bath, while the known quantum speedup was limited to sparsely connected systems. In this work, we give a quantum algorithm with an exponential speedup, capable of simulating d system degrees of freedom coupled to $N = 2^n \gg d$ bath degrees of freedom, to time t and within error ϵ, using $O(\mathrm{poly}(d, n, t, \epsilon^{-1}))$ gates. Significantly, this allows the simulation of non-Markovian baths with finite memory.

References

[1] R. Babbush, D. W. Berry, R. Kothari, R. D. Somma, and N. Wiebe, Phys. Rev. X 13, 041041 (2023)

Figures

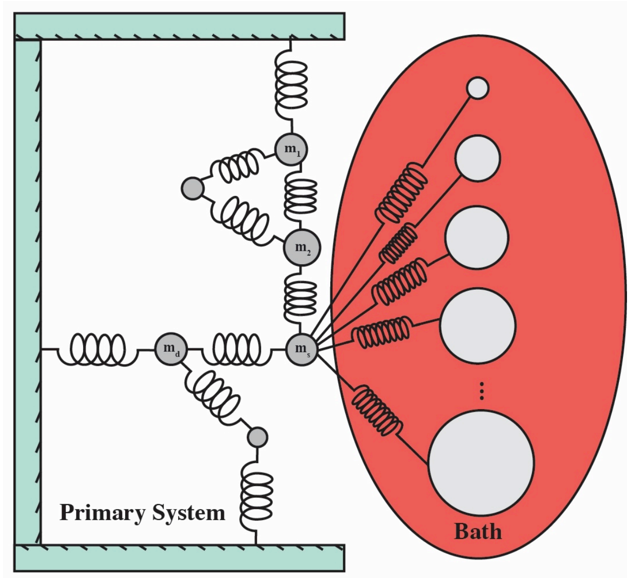

Figure 1: An example of a system coupled to a bath represented by the Caldeira-Leggett model. A finite number of primary system degrees of freedom with are quadratically coupled to each other. A single mass is coupled to a dissipative bath, modeled by an exponentially large number of independent degrees of freedom at with different frequencies.

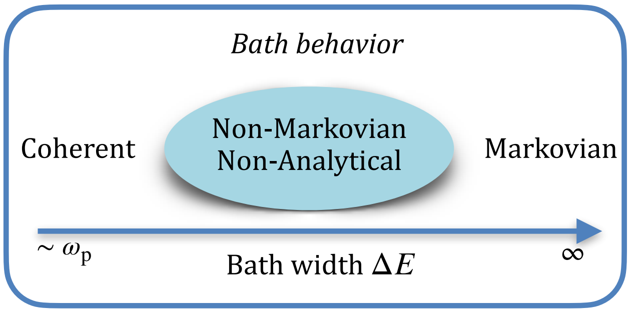

Figure 2: Bath regimes. If the bath oscillators have a narrow frequency range they add a coherent frequency to the system. At the other extreme, an infinite bath adds Markovian dissipation. The intermediate, non-analytical regime can be accessed via a quantum algorithm.