Demonstration of system-bath physics on a gate-based quantum computer

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Algorithmic cooling can be used to find correlated states of many-body quantum systems. It is based on quantum circuits that perform nonunitary operations, whose implementation can be challenging on near-term quantum computers. In this work we develop a method that uses inherent qubit noise to implement nonunitary operations and algorithmic cooling. In our approach, qubit decay during quantum computation is used to simulate dissipation of auxiliary-spin bath, which cools down a simulated system towards its ground state. We test the algorithm on IBM-Q devices and demonstrate the relaxation of system spins to ferromagnetic and antiferromagnetic ordering, controlled by the definition of the system Hamiltonian. The ordering is stable as long as the algorithm is run. We are able to perform cooling and state stabilization for global systems of up to three system spins and four auxiliary spins. Our work paves the way for useful quantum simulations of many-body quantum systems on near-term quantum computers.

References

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Figures

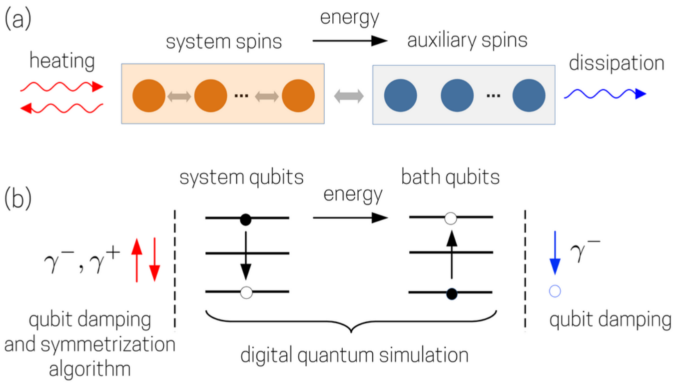

Figure 1: (a) We consider an open-system model where a quantum system of spins is cooled towards its ground state via coupling to auxiliary spins with dissipation. Cooling is a result of resonant interaction between the system and the auxiliary spins with damping. (b) On the gate-based quantum computer with qubit damping, the energy-level structure and the time evolution of the global system is implemented digitally, whereas the dissipation of the auxiliary spins is a result of bath-qubit damping. The simulated system is also connected to an additional environment causing random transitions between its energy levels and thereby heating. The origin of this is system-qubit damping, which is seen as system-spin heating when the introduced time-propagation algorithm is used.

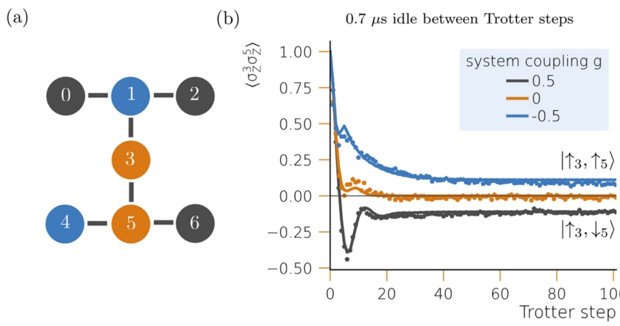

Figure 2: Time-evolving a system-bath model consisting of two system spins coupled to two auxiliary spins on the IBM-Q Lagos device. (a) The selection of the system qubits and bath qubits on the IBM-Q Lagos device. (b) The measured (dots)

and numerically simulated (solid lines) expectation values of the system operator $\hat{\sigma}^{s,1}\hat{\sigma}^{s,2} \propto \hat{H}_S$, revealing the preferred spin ordering in the steady-state. We always start the simulation from all spins being in the state $|\uparrow\rangle$ and vary the inner-system spin-spin coupling g. The interaction with the auxiliary-spin bath makes the system prefer lowest-energy system eigenstates in the steady-state, which are defined by the sign of the coupling g. When we set the coupling g = 0, the measured steady-state value is close to zero. In this simulation we use two (additional) idling phases of 0.7 μs in each Trotter circuit.