Floquet quantum simulation

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A quantum simulator is a programmable quantum device, which can mimic the complex quantum system of interest. Given the difficulty for classical treatment of quantum objects, it can potentially allow access to the physics of medium size molecules and frustrated spin lattices, thus solving open problems of quantum chemistry and magnetism.

Typically the quantum simulation can be divided into two separate types: a digital simulation and an analog simulation (emulation). A digital quantum simulation approach relies on discretization of the Hamiltonian evolution using a set of quantum gates. The digital technique has the advantage of being potentially universal and does not depend on the details of the exploited experimental platform. However, typically it requires exploitation of the Trotterization technique, where a fixed product of unitary operators (Trotter step) is repeated many times. Thus it only works in the systems where many quantum gates of very high fidelity are accessible.

An analog quantum simulation approach is based on the engineering of the Hamiltonian of interest in the physical setup, using interactions and controls native to the platform. This allows to largely simplify the simulation and achieve higher fidelities for a restricted operation time, thus being profitable for all modern setups (e.g. atoms in optical lattices, trapped ions, and superconducting qubits). However, the requirement of being able to construct a physical implementation of a tunable Hamiltonian is an obstacle for reconfigurable quantum simulation, and thus makes it very model-specific. Considering the huge interest in quantum simulators, the natural question to ask is: can one join the advantages of an analog and a digital approach?

In the talk we will discuss a Floquet quantum simulation strategy, which bridges the gap between the two simulator types. It relies on the time-dependent modulation of the Hamiltonian $H(t) = H_0 + H_1(t)$, where H_0 is a time-independent part, and $H_1(t) = H_1(t + 2\pi/\omega)$ is periodic, with ω being the frequency of the modulation. When ω is larger than all other frequencies in the Hamiltonian, the dynamics of the system at integer numbers of periods can be described by an effective Floquet Hamiltonian H_F, which can be qualitatively different from the original static Hamiltonian H_0. This allows to engineer various H_F for the system simply by manipulating drive parameters, thus yielding reconfigurable approach to an analog-like quantum simulation. This approach for instance has been applied to shaken optical lattices, and shown to generate effective gauge fields for atoms [1].

We show how Floquet quantum simulation approach can be used for accessing the physics of spin systems using nonlinear superconducting circuits (SC) to represent a chain of qubits (see sketch in Fig. 1). The algorithm relies on fast time modulation of an effective magnetic field for the qubits, such that starting from the isotropic flip-flop interaction, different types of two-qubit couplings can be engineered. The resulting time-averaged Floquet Hamiltonian is of the generic Heisenberg XYZ type, and is controllable by the drive parameters. As examples we show recipes for designing transverse Ising and non-stoquastic XYZ Hamiltonians, and simulate annealing to the ground state of each configuration [2]. Considering the imperfections of SC, corresponding to finite anharmonicity and the associated leakage, we find that the Floquet approach outperforms digital simulation unless ultrahigh fidelity gates are used for the digital approach. For realistic parameters the procedure allows closely following the ideal continuous annealing, yielding a fidelity corresponding to the one achievable by digital evolution with many (>15) Trotter steps. Finally, we show that access to topologically nontrivial generalized cluster and dual cluster Hamiltonians can be attained in the currently existing setups, where the amplitude of the flip-flop interqubit coupling can be modulated in time.

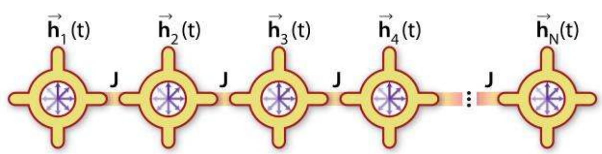

Figure 1. A chain of superconducting qubits coupled through isotropic XY coupling J, each subject to a periodically modulated effective magnetic field $h_j(t)$.

[1] N. Goldman and J. Dalibard, Phys. Rev. X 4, 031027 (2014).
[2] O. Kyriienko and A. S. Sørensen, arXiv:1703.04827 (2017).