Discrete Time Crystals on Quantum Computers using Qiskit

The goal of this project is to implement a discrete time crystal (DTC) in a (quantum) simulation using IBM's software package Qiskit. You will learn to write simulations in Qiskit, and become familiar with the effect of noise. In particular, we will consider the Floquet unitary

$$U_F = \mathrm{e}^{-\frac{i}{2}\sum_i h_i Z_i}\ \mathrm{e}^{-\frac{i}{4}\sum_i \phi_i Z_i Z_{i+1}}\ \mathrm{e}^{-\frac{i}{2}\pi g \sum_i X_i}, \tag{1}$$

where X_j (Z_j) denote the Pauli matrices; each ϕ_i is sampled uniformly at random from $[-1.5\pi, -0.5\pi]$ and each h_i is sampled uniformly at random from $[-\pi, +\pi]$. The parameter g is set within the range $[0.5, 1.0]$ to explore the transition between a DTC and thermal phase. This project is based on the paper *Time-crystalline eigenstate order on a quantum processor* by Mi *et al.*, Nature volume 601, 531–536 (2022). This project is numerical. Prior familiarity with Qiskit is required (or prepare to work harder!).

- Make yourself familiar with Qiskit; you should learn how to build circuits, and how to apply gates generated by the X, Z and ZZ operators, with a preset gate angle.
- Using Qiskit, implement the unitary U_F in a dissipation-free and noise-free simulation. Play with the model parameters and try to observe both the MBL-DTC and the thermal phase. What is a proper initial state to start from?
- Optional goal: Use one of Qiskit's noise models and investigate the effect of noise on the DTC signal. Can you apply the noise-mitigation technique from the paper above?
- Optional goal: modify your circuit to implement the circuit from Fig. 4a from the paper.
- Optional goal: Run your circuit on an actual IBM machine (you can register online at IBM Quantum to get access).

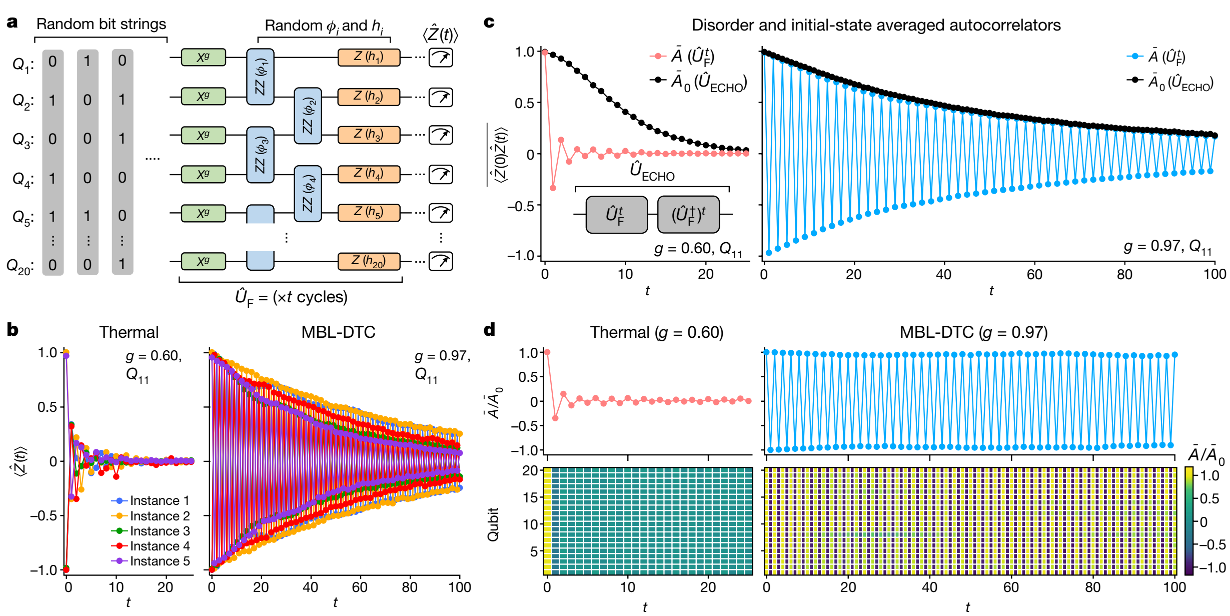

Figure 1: DTC on a quantum computer. (For more details, see reference.)