IBM Quantum Creative Challenge

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1 Introduction

The oscillation of qubits create waves. The oscillation of multiple qubits with different initial states generates constructive and destructive interference due to the superposition of the qubits. In this report, we present quantum interference using Qiskit circuits, an open source framework developed by IBM. In this work, we introduce Mixed field Ising model [1, 2] in order to generate the interference using 14 qubits. The Hamiltonian of Mixed field Ising model is defined as follows:

$$H = V \sum_{\langle i,j \rangle} Z_i Z_j + \Omega \sum_i X_i + h \sum_i Z_i, \tag{1.1}$$

where: i and j are nearest neighbors; Z_i, and X_i are Pauli matrices; V is the nearest neighbor interaction strength; Ω is the coupling strength of the transverse field magnitude; h is the magnetic field amplitude.

The first term of the Hamiltonian is the nearest neighbors interaction and the second and third term are the magnetic field and spin interaction terms. The nearest neighbors interaction generates waves from the qubits as the sources, and the interference is decided by the initial states of the 14 qubit. We create the Trotter circuit[3] in order to simulate the time-evolution with arbitrary initial states using the Mixed field Ising model.

2 Problem Formulation

Due to the Trotter expansion approximation, the time step should be smaller than 1. Based on the paper[4], smaller transverse magnetic field is selected in order to obtain obvious interference patterns. If Ω and the time steps are too small, we cannot see any dynamics from the time evolution plots. Therefore, it is crucial to choose appropriate and suitable parameters in order to manifest clear interference patterns on the the time evolution $<Z_i>$.

3 Experiment and Discussion

We apply exact diagonalization to obtain interference parameters in order to utilize the parameters in the Trotter circuit, as shown in Fig. 1. The adjustable parameters include Ω, h, V, T, NT, where NT stands for the number of steps.

We select 8 different initial states in order to show the interference using the time-evolution Trotter circuit. Fig. fig:maps show the relation between the interference and the initial states. In order to see obvious interference on the plot, the choices of the initial state is crucial.

In Fig. 2 (c) and (h), the initial states generate interference patterns on the images. In Fig. 2 (c) and (f), the plots show a one-point source of 2-dimensional wave pattern. The waves interfere with themselves because the periodic boundary is considered in our model. In Fig. 2 (g) and (h), the plots show two-point source 2-dimensional waves, in which the waves interfere with each other. In Fig. 2 (e) and (d), the plots show the multiple point source 2 dimensional waves. With the initial state of 01010101010101 and 00000000000000 as shown in Fig. 2 (a) and (b), no interference is shown on the patterns.

4 Future implications

In this work, we present the interference using the time-evolution Trotter circuit simulation. Interference in quantum circuit plays an important role since it is used to serve as a useful benchmark for quantum hardware improvements.

For more information, refer to https://github.com/Hui-Ying/IBM-Quantum-Creative-Challenge.

References

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[4] Federica M. Surace et al. "Lattice Gauge Theories and String Dynamics in Rydberg Atom Quantum Simulators." In: *Phys. Rev. X* 10 (2 May 2020), p. 021041. DOI: 10.1103/PhysRevX.10.021041. URL: https://link.aps.org/doi/10.1103/PhysRevX.10.021041.

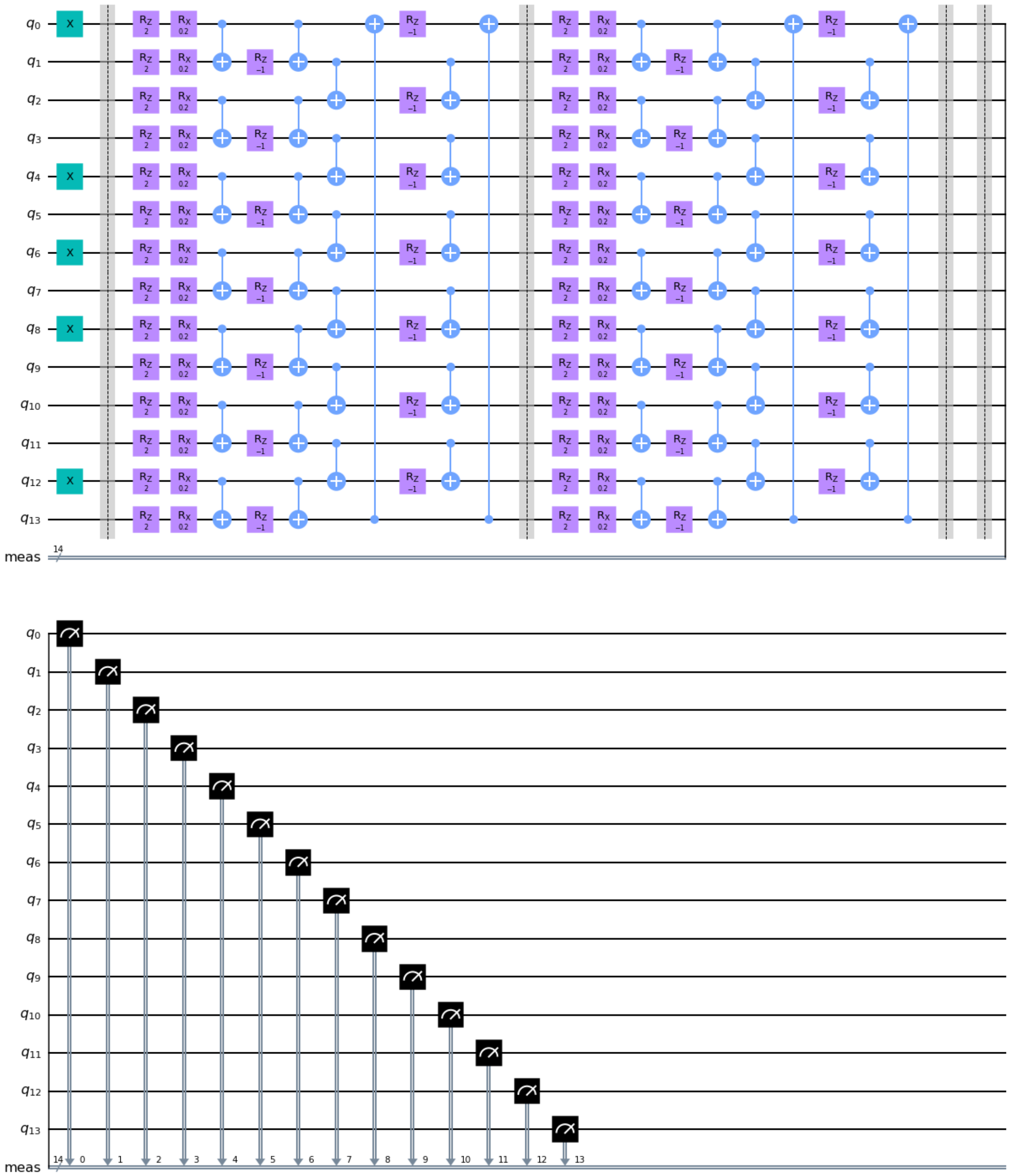

Figure 1: Qiskit circuit schematic for the Trotter circuit with initial state of 1000101010001

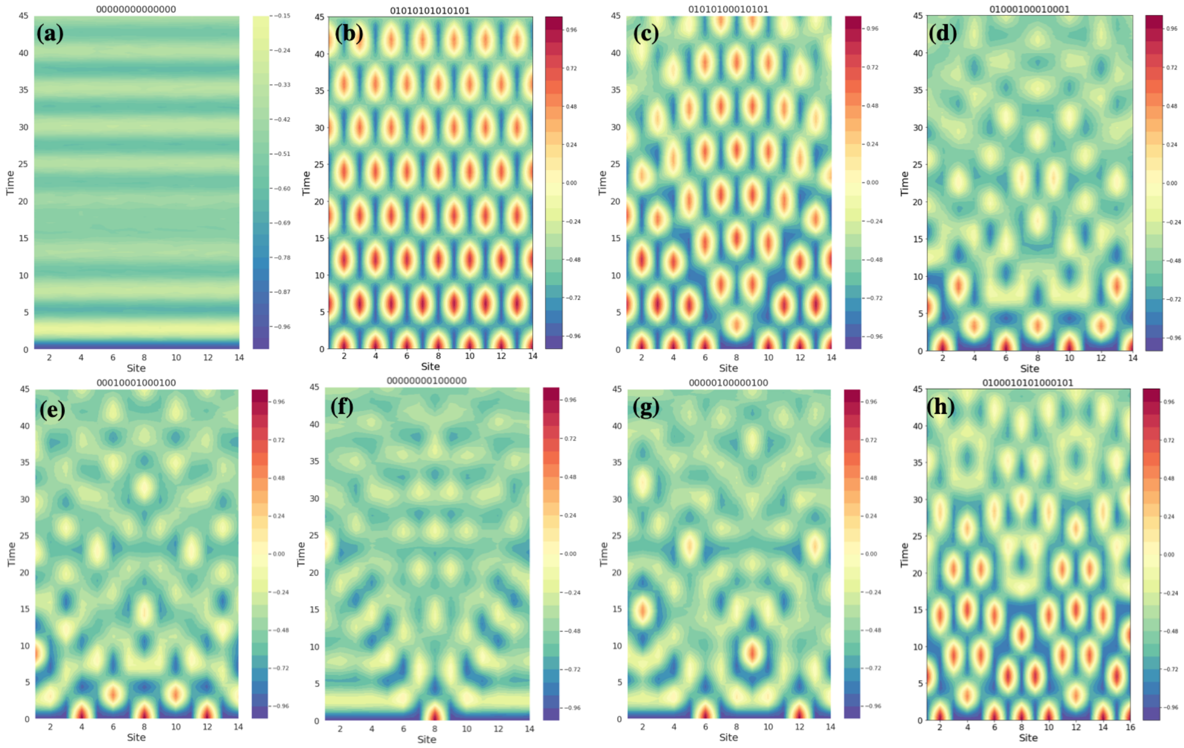

Figure 2: Qiskit circuit schematics for the Trotter circuit with 8 different initial states.