Week 1: Simulating quantum advantage with trapped ions

Team 10: Alexander (Sandy) Bell, Na Young Kim, Sushanta Mitra, Ushnish Ray, Ming-T

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Introduction

We put all the functions for the coding tasks in the script `assignment.jl`.

Task 1

In this task, we create a function `getAmp2` to calculate the probability $P(x) = |\langle x|\psi\rangle|^2$ of each bit-string x showing as a dot in the speckle pattern by taking the dot product between the bit-string and $|\psi\rangle$ from the `run` function given in the script `run_random_circuit.jl`. In Fig. 1, we plot 16 different combinations of N and circuit depths, where N varies from 2 to 5, and the depths include 4, 16, 32, and 64. These patterns are plotted by the function `speckles()`. One can find that some bitstrings are much more likely to occur than others, especially when N is larger. The location x with highest probability seems to distribute randomly.

We also make a function `studyBondDim` to calculate the bond dimension in the bonus problem by using the built-in function `maxlinkdim` in ITensor. In Fig. 2, we plot the bond dimensions as a function of circuit depth at several values of N. The bond dimension saturates at a higher circuit depth when N is larger.

Task 2

To consider a single random bit flip, we modified the given `run` function by adding an argument `wbitflip`. If `wbitflip` is `True`, we assign a bit flip at a random location `bitloc` in the modified `run` function. In the `bitFlipCompile` function, we let `wbitflip=True` and plot 16 different speckle patterns generated from a single bit flip error of a single gate and collect them into a collage, as shown in Fig. 3.

Task 3

In this task, we create a function `cgfScalingSingle` to calculate the cumulative distribution function (CDF) by numerically summing or integrating the probability distribution. Then we use the function `cgfScaling` to plot the CDF values with different depths and compare them with the theoretical value $1 - e^{-2^N p}$, as shown in Fig. 4

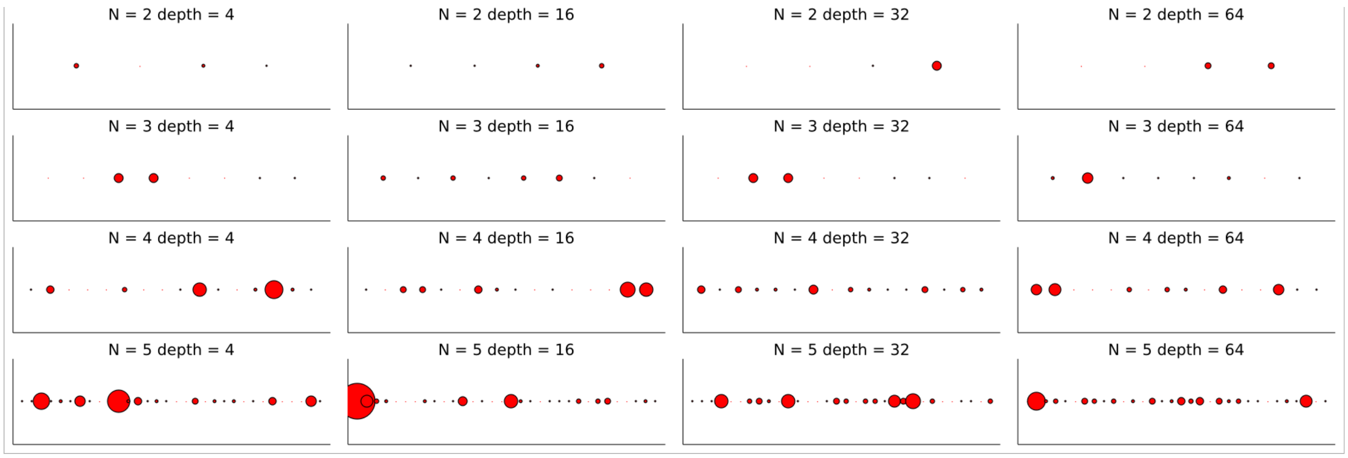

Figure 1: "Speckle patterns" displaying the probabilities of obtaining with $N = 2$ to 5 and depths of 4, 16, 32, and 64.

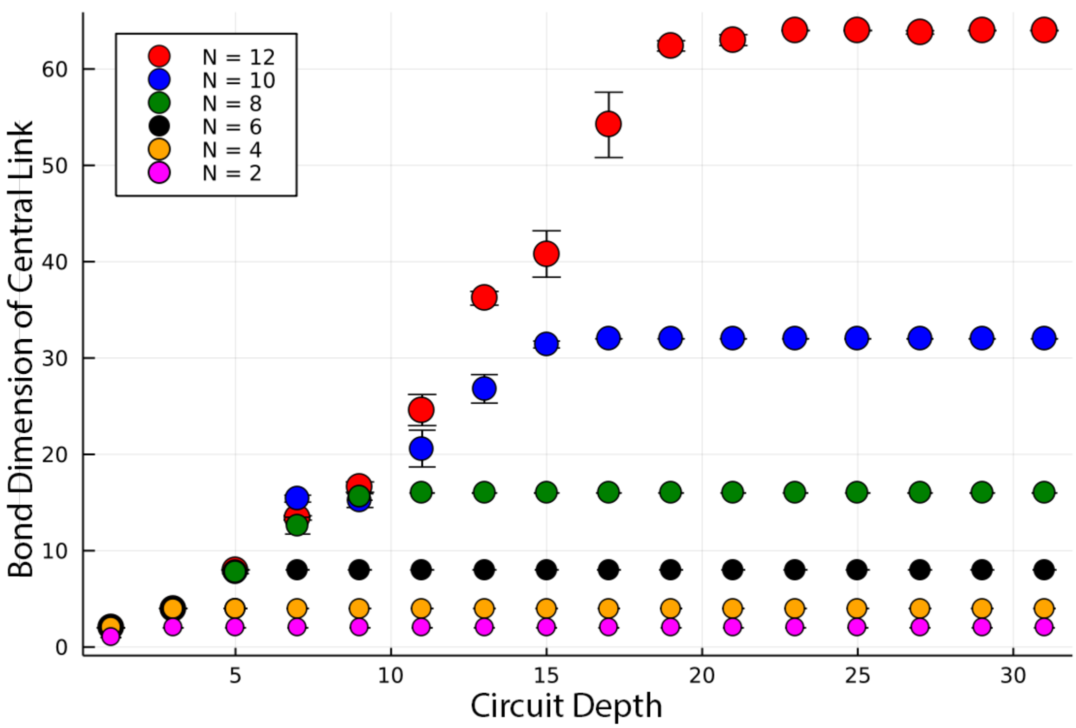

Figure 2: The bond dimensions of central links as a function of circuit depth at different numbers of qubits. At a

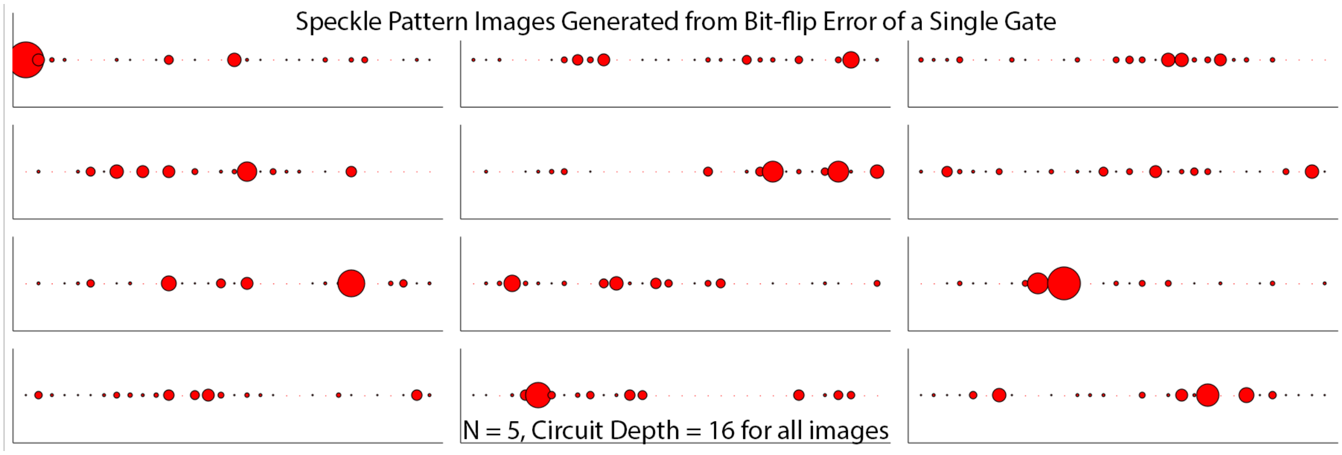

Figure 3: "Speckle patterns" displaying the probabilities of obtaining each of the 16 possible outcomes when sampling a 5-qubit circuit with a bit flip error occurred at a random location.

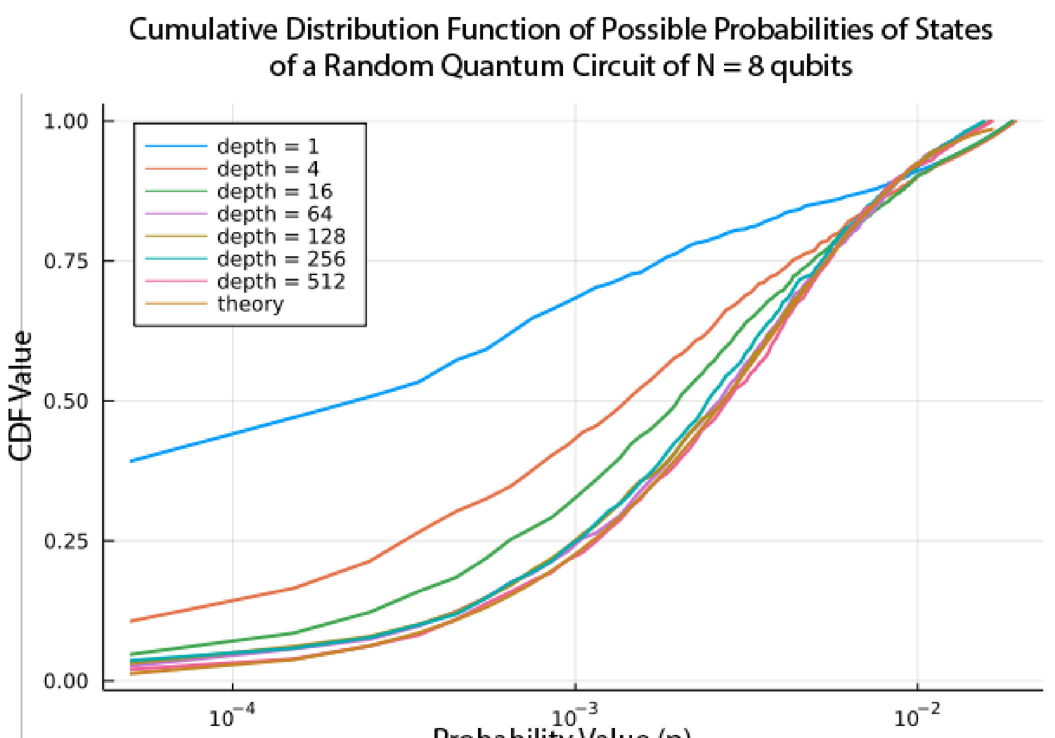

Figure 4: Calculated CDF as a function of the probability values p in log scale at different circuit depths in an 8-qubit circuit. When the depth is larger, the CDF converges toward the theoretical value $1 - e^{-2^N p}$.

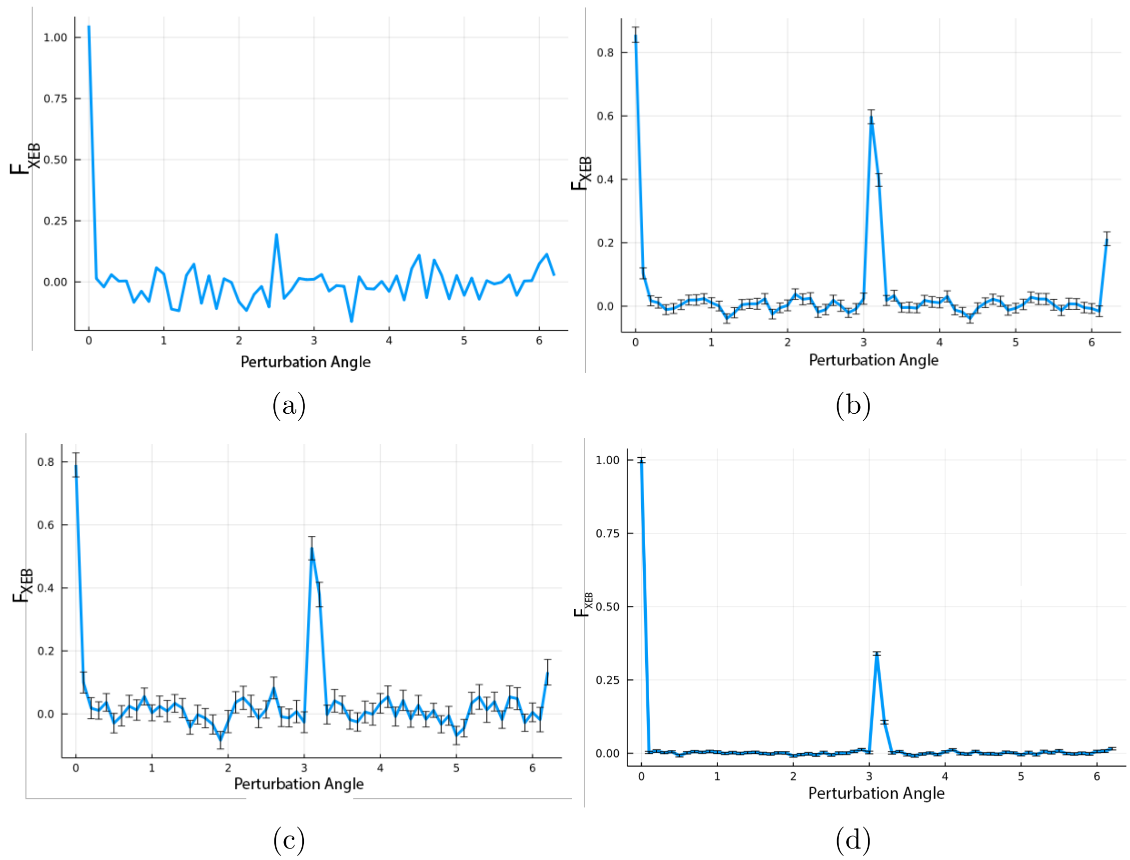

Figure 5: The crossed entropy benchmarking fidelity $\mathcal{F}_{\mathrm{XEB}}$ calculated as a function of the perturbation angle $\Delta\Theta$ in a unit of radians at different numbers of qubit N, circuit depths d, and numbers of samples s. (a) N=8, d=512, without averaging; (b) N=4, d= 128, s=200; (c) N=8, d=128, s=50; (d) N=10, d=128, s=50.

Task 4

In the function `crossEntropyValue`, we calculate the linear cross-entropy benchmarking (XEB) fidelity $\mathcal{F}_{\mathrm{XEB}}$, defined in Eq. (1) of the instruction. In Fig. 5(a), the function `crossEntropy` assembles the results at different $\Delta\Theta$ and plots the $\mathcal{F}_{\mathrm{XEB}}$ as a function of $\Delta\Theta$.

In the function `crossEntropywDavg`, $\mathcal{F}_{\mathrm{XEB}}$ is calculated by averaging over a certain number of samples s. In Figs. 5 (b) - (d), we calculate the XEB fidelity $\mathcal{F}_{\mathrm{XEB}}$ when performing the averages over a number of samples s. A peak occurs near $\Delta\Theta = \pi$.

Business Application