Time Reversal Project Report

CS 309: Quantum Computing

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Time Arrow of Reversal Algorithm and Execution

Overview:

Contrary to popular belief, the authors did not send themselves or their computer back in time. The widespread reports of the authors going backwards in time for amounts varying from a few seconds to microseconds are materially false and grossly misrepresent the actual experiment. The results demonstrated in this experiment can not in fact be used to meet Caesar or warn our predecessors of the dangers of CFCs. What the authors actually accomplished was a localized reversal of entropy: quite simply, a certain scattering phenomenon was simulated and allowed to become increasingly complex before being reverted to a time-reversed state that naturally decreases in entropy by a forced series of operations. The authors note that the appearance of the setup required for this operation to take place is highly improbable in nature to the point that it is practically impossible: “For the time reversal one needs a supersystem manipulating the system in question. In most of the cases, such a supersystem cannot spontaneously emerge in nature.” It is further demonstrated that even if such a supersystem were to naturally emerge, it would be practically impossible for the conditions to align such that it would actually result in a time reversal: “Even if such a supersystem would emerge for some specific situation, the corresponding spontaneous time reversal typically requires times exceeding the universe lifetime.” These constraints lead UT quantum information center director Scott Aaronson to remark: “If you’re simulating a time-reversible process on your computer, then you can ‘reverse the direction of time’ by simply reversing the direction of your simulation. From a quick look at the paper, I confess that I didn’t understand how this becomes more profound if the simulation is being done on IBM’s quantum computer.”

Challenges:

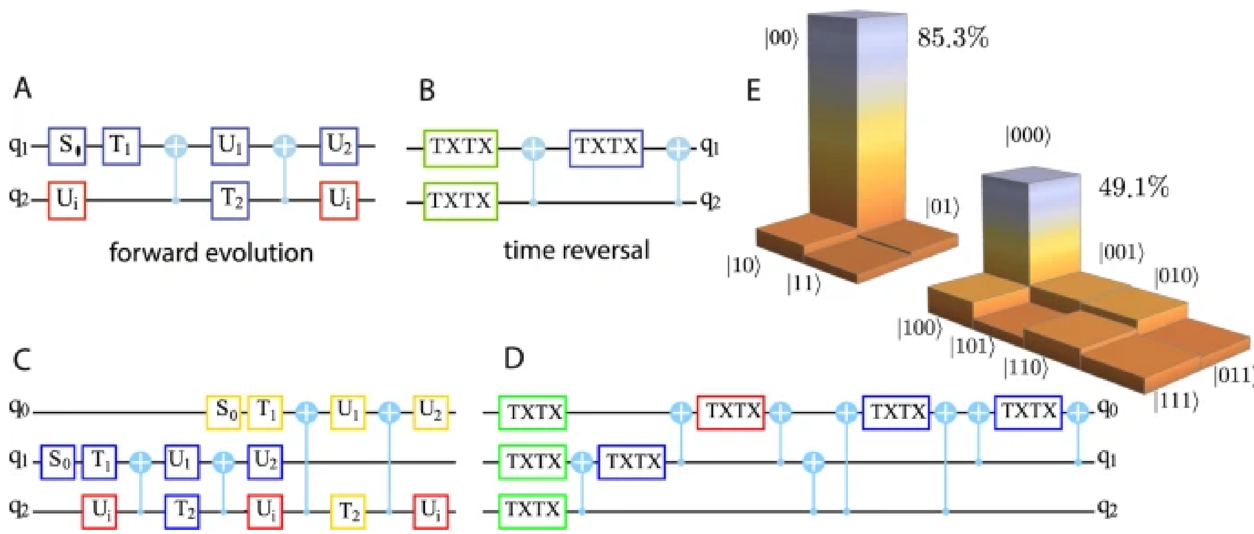
However, while it soon became very clear that the experiment did not in fact result in “time travel” in the sense that we would typically associate with the term, reproducing the authors’ results proved to be immensely challenging and required significant effort on our part. The paper was filled with technical jargon and a large amount of complicated mathematics that went far beyond the scope of our course, and it was quite difficult to piece all the scattered parts together. It didn’t help that we initially neglected the existence of a supplemental information form explaining much of the work and instead tried to reproduce the requisite gates by doing the relevant calculations ourselves. In doing so, we ran into a multitude of rabbit holes and “learned” some useful mathematics regarding the interplay of Hamiltonians, forward time evolution mechanics, and the Schroedinger equation along the way while mostly just confusing ourselves. It did not help that the authors decided to employ the full extent of their computer science knowledge in embarking upon numerous strange quantum computing optimizations that only served to further muddy the waters. After eventually coming upon the supplemental information section, we were able to immediately reproduce most of the experimental setup with the provided information and some of what we learned throughout the semester, with most of the documentation proving sufficient excepting the parameters for the TXTX matrix, which we were unable to figure out as it was not mentioned in the supplemental information sheet and left for later.

However, when we then tried to run the program, we discovered that IBM would not allow us to input decimal results and we would thus have to derive the parameters ourselves given what was by now recognized as the extremely useful extra information provided in the supplemental information section. Calculating the exact parameters for the forward evolution operator Ui used in the experiment was quite simple once we realized how the equations given fit together. After puzzling through the "general algorithm" section of the main paper and the "boolean function" of the supplemental information we were still unable to figure out what exactly the respective inputs for the T(a/b) portions were intended to be and sought outside help to resolve this issue.

Our Procedure:

Our methodology to recreate the time-reversal experiment are based on the three steps outlined in the paper: First, we take an initially set qubit register $|\psi(0)\rangle = |0 \ldots 0\rangle$ and then apply the unitary forward time evolution onto $|\psi_0\rangle$, then this will produce the evolution over time of this initial state; thus, the time evolved state is $|\psi_1\rangle = \hat{U}_{nbit}|\psi_0\rangle$. Second, we apply the complex unitary conjugation operation $\kappa = \hat{U}_{\psi}$ to $|\psi_1\rangle$ to yield $|\psi^*_1\rangle$ to which we apply the unitary rotation U_R to prepare the "time-reversed" state $|R\psi_1\rangle$. Third, we apply the unitary forward time evolution on $|R\psi_1\rangle$ which measures the resulting qubit register in the computational basis. This measurement should result in the initial $|\psi_0\rangle$ state. The process described in the Nature report can be seen below in Figure 1 (Figure 2 in the Nature report) for two qubits and three qubits.

Figure 1

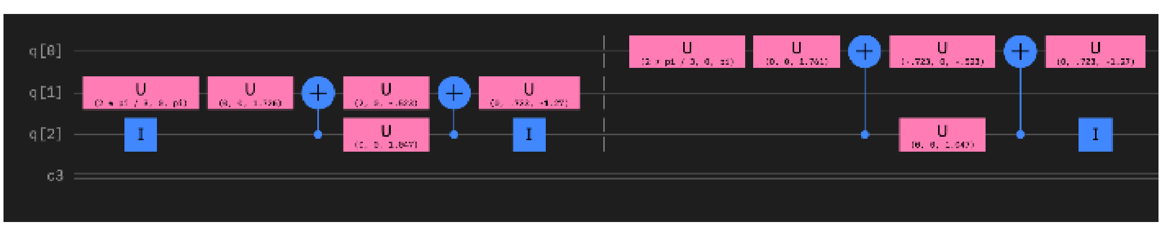


(Figures 1.A and 1.B represent the process for two qubits and 1.C and 1.D represents the process for three qubits. Figure 1.E shows their measured data. Also note that this figure does not include the Step 3 that was descibribed above)

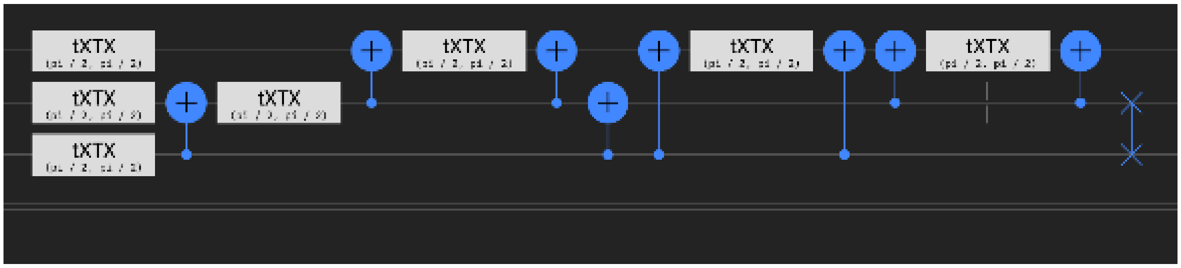
Using these steps and the provided Figure 1, we attemtped to recreate the experiment in IBM Quantum Composer. Our attempt can be seen below in Figure 2 (a higher resolution image will be provided along with this report).

Figure 2

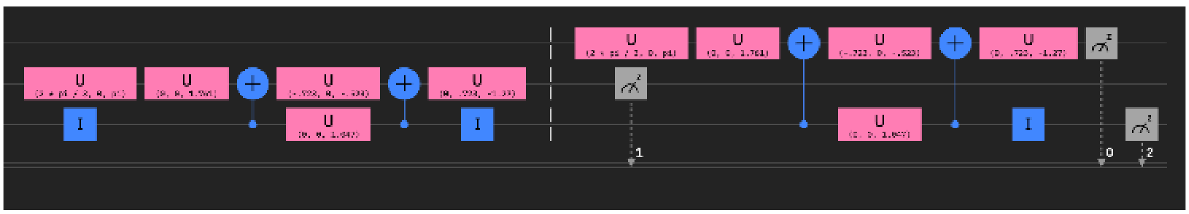
Step 1



Step 2



Step 3

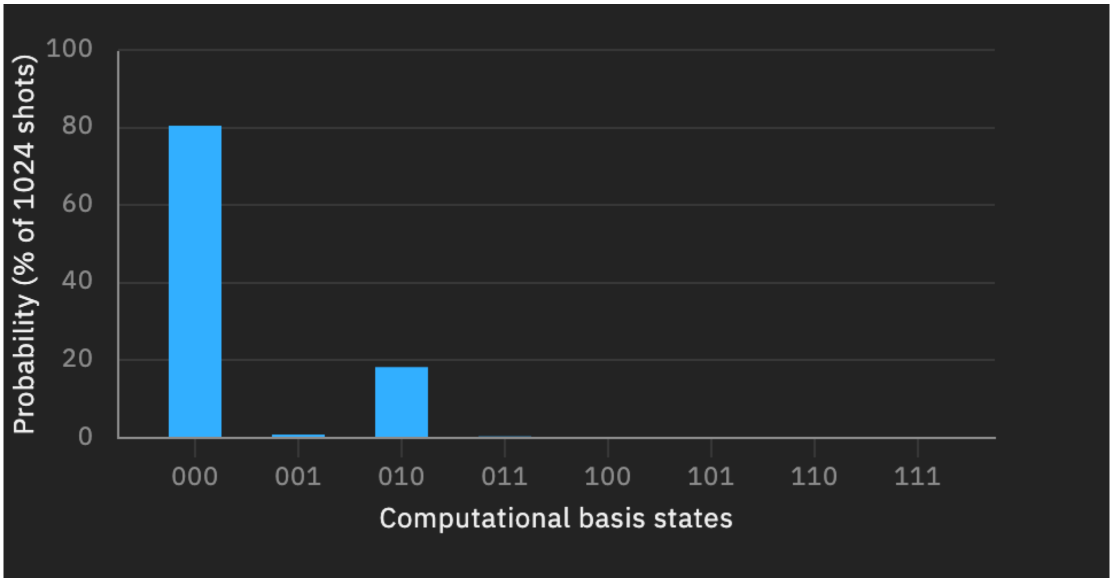


As seen above, we have implemented the procedure for three qubits using the three steps presented in the Nature report as per our understanding. Although abstruse, we deduced the values used in the original experiment by backtracking formulas and data provided in the Supplementary Information document for the report. There was still some obscurity as to the TXTX implementation as we were unsure what the parameters for the T gates are supposed to be— we just assumed the parameter to be the same as the second parameter for the unitary gate. We reached out to the class TA's to check if our assumption for the TXTX parameters were correct. The parameters did seem to be correct, and so it became unclear as to what was missing or incorrect from our composer. However, after a closer analysis of the Nature report, we had apparently forgotten to place a $SWAP_{12}$ gate in our composer. The report stated that for the three qubit system, we needed to sandwich the prepared unitary state with two $SWAP_{12}$ gates ($SWAP_{12} \cdot \hat{U}_{3bit} \cdot SWAP_{12} = \hat{U}^{t}_{3bit}$). This meant we needed to place a $SWAP_{12}$ between steps 1 and 2 and steps 2 and 3. The Nature report states that this extra SWAP gate provides more efficiency as it physically swaps the qubits rather than creating a new unitary rotation matrix ($\hat{U}_R = SWAP_{12}$) and using an additional three CNOT gates. The IBM computers do have a limitation on the amount of implemented CNOT gates due to the error rate of its CNOT gates; so, replacing step 2 ($\hat{U}_R = SWAP_{12}$) with the $\hat{U}^t_{3bit}$ instead, the error in the results is minimized with the reduction of three CNOT gates. Thus, with this addition of the $SWAP_{12}$ gate, our statevector was finally $|000\rangle$ with a phase angle of 3.3958, slightly greater than π.

Results

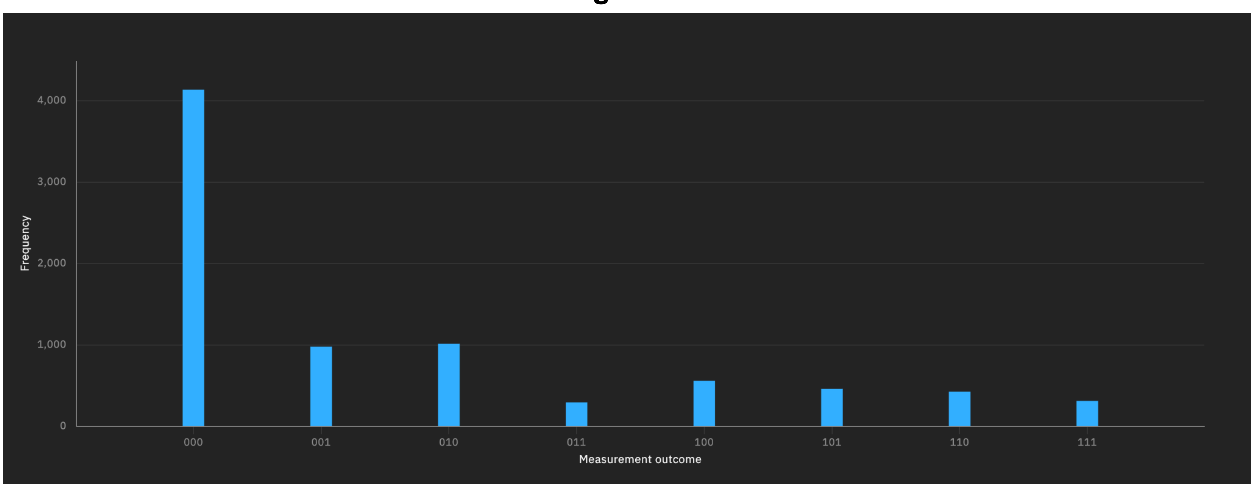
After finalizing the circuit, we ran this circuit on "ibmq_quito" with 8192 shots. The distribution of results were as expected, the majority of measurements resulted in $|000\rangle$ state with the second most being $|010\rangle$ state. The distribution matched the theoretical distribution; however, the percentage of each result was different (especially the $|000\rangle$ state) (*see Figure 4*). The theoretical probability was roughly 80.47% for $|000\rangle$ and 18.26% for $|010\rangle$ (*see Figure 3*); however, in the experimental results, the outcome was roughly 50.52% $|000\rangle$ and 12.39% $|010\rangle$. This may be due to the noise present in the quantum computer and maybe with the hardware of the particular computer we used. Though, the distribution of the measurement outcomes do match.

Figure 3



(This is the theoretical probability of the measurement outcome for each state)

Figure 4



(This is the plot for the experimental results)

Conclusion

Based on the results, we can conclude that the distribution of our results match the distribution of the experimental results presented in the Nature report.