QuEra 2025 Challenge Write Up

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1 Introduction

One of the most exciting part about quantum computing is the different technologies that exists and their tradeoffs. For us, the QuEra challenge presented a unique opportunity to learn about the neutral atom technology and take advantage of the topology and the different 'sections' nature and how they can decrease running time and increase coherence.

2 Background

2.1 Gate Decomposition

One of the first challenges we faced was to decompose the different gates into the basis gates of $cz, R_z, \text{and} R_{xy}$ gates. To do this, we utilized online resources and matrix calculators to calculate the Kronecker product. In the end, some notable decomposition of gates include:

- $H = R_z(\pi/2)R_x(\pi/2)R_z(\pi/2)$
- $\text{CNOT} = HC_zH$
- $Cr_z(\theta) = R_z(\theta/2)\text{CNOT}R_z(-\theta/2)\text{CNOT}$

2.2 Gate Recombination & Elimination

After decomposing the circuit gates, with the help of reference 4 in the challenge document, we were able to perform many rules to further simplify the circuits. The first rule is the fact that the R_z gate commutes with the C_z gate, allowing us to combine the coefficient of the rotation. This allows us to exchange X gate with the R_z gate based on rule ac) from the reference (Allowing a $R_z(\alpha)X = XR_z(-\alpha)$). Finally, we took advantage of the fact that gates like H gate are Hermitian, allowing us to significantly cut down on the number of gates used.

2.3 Expense Minimization

The final step for our routine is to minimize the cost. To do this, we first try to minimize the amount of C_z required by reconfiguring the qubits to allow parallelization (as demonstrated in the GHZ example). This allows us to cut down on the most costly operation. The next big saving is recognizing global gates that can be applied, either by the nature of the circuit or the fact that the gates applied globally will result in a rotation of 2π. Finally, we attempt to maximize the amount of operations per time to cut down on the total time of the circuit.

3 Methodology

For this challenge, we heavily utilized the Quantum Composer by IBM to allow us to visually breakdown and recombine the gates. Furthermore, this decision helped us to keep track of the relative phase (as well as the global phase) for the solution. This allowed us to check whether or not our solution matches the given circuit in an ideal condition.

4 Result

Problem #	Final Cost
1.1	7.5
1.2	24.1
2	23.8
3	86.96
4	38.4
5	40.3

Table 1: A simple table with two columns

5 Discussion

Overall, we were really happy with our result as we were able to see a significant decrease for several problems. In particular, we were able to consistently 26% decrease in the cost of the circuit. In particular, with the tofolli gate and the circuit in problem 4 and 5, with globalization and clever Cz movements, we were able to successfully lower the cost of the circuit despite the massive amount of gates generated when first broken down.

One interesting thing to note during the challenge is that we discovered that the QASM checker is often mistaken as it only considers whether the two density matrix is exactly the same. This fails to take into account the global phase that will be introduced during the process (and is something that cannot be observed physically and thus is a postulate in quantum mechanics that global phases do not matter). Overall, this was a very enjoyable challenge and one that we were able to learn a great deal with along with some fun in the journey.