iQuHACK 2026 Challenge

Superquantum

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1 Challenge overview

Your goal is to compile 2-qubit quantum circuits into a sequences of Clifford+T gates, i.e., the gates generated by $\{H, S, T, CNOT\}$ operations. You can find the specifics on these circuits in the next section. Each subsequent compilation task is meant to be a little more involved than a previous ones. Also, many consequential pairs of circuits are related, so try to really understand the structure of your solutions.

The topic of Clifford+T compilation is rich and mature, so there are a lot of useful references you can find online that will help you with the challenge. You might find the following paper and corresponding software handy: Refs. [1, 2]. You are also welcome to use Superquantum's very own RMSYNTH compiler [3]. Note, however, that you are *not* required to use any particular software, but we ask you to submit your quantum circuits as QASM files. More on that in Section 3.

2 Unitaries to compile & scoring

1. Controlled-Y Gate: $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -i \\ 0 & 0 & i & 0 \end{bmatrix}$.

   This is just a sanity check to make sure you understand the task and that the submission works properly.

2. Controlled-Ry($\pi/7$): $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -0.22 - 0.97i \\ 0 & 0 & 0.22 + 0.97i & 0 \end{bmatrix}$.

   Here, you will really need to apply your compilers!

3. Exponential of a Pauli string: $\exp(i\frac{\pi}{7} Z \otimes Z)$.

   This is a crucial ingredient in quantum simulation algorithms.

4. Exponential of a Hamiltonian $H_1 = XX + YY$: $\exp(i\frac{\pi}{7}H_1)$.

   Think about the structure of the summands in H_1.

5. Exponential of a Hamiltonian $H_2 = XX + YY + ZZ$: $\exp(i\frac{\pi}{2}H_2)$.

   Think about the structure of the terms as well as the matrix form. Does it resemble anything? The compiled circuit is easier than you might think.

6. Exponential of a Hamiltonian: $H_3 = XX + ZI + IZ$: $\exp(i\frac{\pi}{7}H_3)$.

   This is a time evolution under a 2-qubit transverse field Ising model.

7. State preparation. Design $U \in \mathbb{C}^{4\times 4}$ that maps

$$
\begin{aligned}
|00\rangle \mapsto\ & (0.1061479384 - 0.679641467i)|00\rangle \\
& +(-0.3622775887 - 0.453613136i)|01\rangle \\
& +(0.2614190429 + 0.0445330969i)|10\rangle \\
& +(0.3276449279 - 0.1101628411i)|11\rangle.
\end{aligned}
$$

   Preparation of arbitrary quantum states is an important and a notoriously hard task in quantum computing. Note that there are many unitaries that can perform this mapping. We ask you to submit the one for which you obtain the best metrics.

   In case relevant, this state is generated via
   `qiskit.quantum_info.random_statevector(4, seed=42)`.

8. Structured unitary 1:

$$
\frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & i & -1 & -i \\ 1 & -1 & 1 & -1 \\ 1 & -i & -1 & i \end{bmatrix}
$$

   .

   Figure out what the structure is! You should be able to efficiently compile it using some of the previous results.

9. Structured unitary 2:

$$
\begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & -\frac{1}{2}+\frac{i}{2} & \frac{1}{2}+\frac{i}{2} \\ 1 & i & 0 & 0 \\ 1 & i & -1+i & 0 \end{bmatrix}
$$

   Same as above – figure out the structure of this gate and it will be easy from there.

10. Random unitary:

$$\begin{bmatrix} 0.1448081895 + 0.1752383997\,i & -0.5189281551 - 0.5242425896\,i & -0.1495585824 + 0.312754999\,i & 0.1691348143 - 0.5053863118\,i \\ -0.9271743926 - 0.0878506193\,i & -0.1126033063 - 0.1818584963\,i & 0.1225587186 + 0.0964028611\,i & -0.2449850904 - 0.0504584131\,i \\ -0.0079842758 - 0.2035507051\,i & -0.3893205530 - 0.0518092515\,i & 0.2605170566 + 0.3286402481\,i & 0.4451730754 + 0.6558933250\,i \\ 0.0313792249 + 0.1961395216\,i & 0.4980474972 + 0.0884604926\,i & 0.3407886532 + 0.7506609982\,i & 0.0146480652 - 0.1575584270\,i \end{bmatrix}$$

11. Diagonal unitary.

    Random quantum circuits are widely used in "quantum supremacy" experiments [4] and are even believed to have connections to black hole physics [5].

    In case relevant, this matrix is generated via `qiskit.quantum_info.random_unitary(4, seed=42)`.

References

[1] P. Selinger and N. J. Ross, *Exact and approximate synthesis of quantum circuits (newsynth package)*, https://www.mathstat.dal.ca/~selinger/newsynth/, Software package for quantum circuit synthesis, 2018.

[2] N. J. Ross and P. Selinger, "Optimal ancilla-free Clifford+T approximation of z-rotations", arXiv preprint arXiv:1403.2975 (2014).

[3] Superquantum, *rmsynth: high-performance Clifford+T circuit optimizer using phase-polynomial methods and punctured reed–muller decoding*, https://github.com/super-quantum/rmsynth, GitHub repository, Apache-2.0 license, 2026.

[4] F. Arute, K. Arya, R. Babbush, D. Bacon, J. C. Bardin, R. Barends, R. Biswas, S. Boixo, F. G. Brandao, D. A. Buell, et al., "Quantum supremacy using a programmable superconducting processor", Nature **574**, 505–510 (2019).

[5] L. Susskind, *Complexity and Gravity*, https://www.youtube.com/watch?v=6OXdhV5BOcY, Prospects in Theoretical Physics 2018: From Qubits to Spacetime (IAS lecture), July 2018.