Hi!

Once again, thank you for your interest in the QC Mentorship program!

We decided to select participants based on how they will manage to do some simple “screening tasks”.

These tasks have been designed to:
- find out if you have the skills necessary to succeed in our program.
- be doable with basic QC knowledge - nothing should be too hard for you to quickly learn.
- allow you to learn some interesting concepts of QC.
- give you some choices depending on your interests.

What we mean by skills is not knowledge and expertise in QC. It’s the ability to code, learn new concepts and to meet deadlines.

What are we looking for in these applications?
- Coding skills – clear, readable, well-structured code
- Communication – well-described results, easy to understand, tidy.
- Reliability – submitted on time, all the points from the task description are met
- Research skills – asking good questions and answering them methodically

Also, feel free to be creative – once you finish the basic version of the task, you can expand it.

Choose tasks based on your interests, don’t try to pick the easiest one.

You need to do only 1 task. Feel free to do all of them, it might be a good learning opportunity, but it won’t affect admissions to the program :)

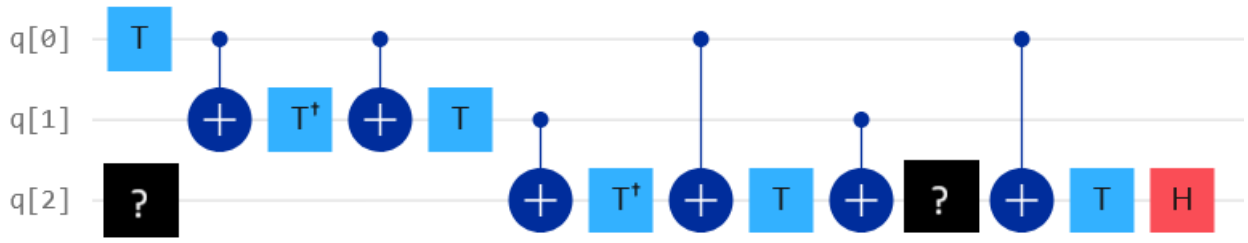
So here are the tasks:

Task 1 Gate Tomography

When designing a set of universal gates, one must prove that any unitary operation can be performed by combining gates of that set, which is known as circuit equivalence. In this case, you have to find the parameters of the U3 gates:

$$U3(\theta,\phi,\lambda) = \begin{pmatrix} \cos\left(\frac{\theta}{2}\right) & -e^{i\lambda}\sin\left(\frac{\theta}{2}\right) \\ e^{i\phi}\sin\left(\frac{\theta}{2}\right) & e^{i(\phi+\lambda)}\cos\left(\frac{\theta}{2}\right) \end{pmatrix}$$

such that the following circuit is equivalent to a Toffoli gate, in which the U3 gates are marked with '?':



NOTE: The parameters of the U3 gates might not be the same for both!

Task 2 Complex Amplitudes

Your goal is to implement a routine that prepares a two-qubit quantum state given a set of complex amplitudes. The solution should be written from scratch, without relying on high-level quantum libraries (e.g., Qiskit's initialize, PennyLane's state preparation templates, etc.). Instead, focus on constructing the state manually using fundamental concepts such as normalization, tensor products, and matrix–vector representations of quantum states and gates.
Requirements

Input: A list or array of four complex amplitudes [a0, a1, a2, a3] that define the desired two-qubit state.

- Ensure that the state is normalized:
  |a0|^2 + |a1|^2 + |a2|^2 + |a3|^2 = 1

- If the input is not normalized, include a normalization step.

A representation of the two-qubit quantum state vector, for example as a NumPy array:
  $|\psi\rangle = a0|00\rangle + a1|01\rangle + a2|10\rangle + a3|11\rangle$

- Do not use quantum-specific state preparation functions from libraries.

4. Testing:
   - Write unit tests that check:
     - Normalization is enforced.
     - The output vector has the correct dimension (4 for two qubits).

Stretch Goal
Generalize the implementation to support a three-qubit state given 8 amplitudes.

Task 3 Error Correction

Error Correction is essential to achieve any quantum advantage in the near future. A basic understanding of the inner workings of the basic error correction tools is essential for any quantum computing scientist. In this task, you will go through these basic tools.

1. Build a function to create a simple noise model. Introduce a random Pauli (X with “a” probability,Z with “b” probability) into any circuit. Test the noise model with simple circuits.

   Example of the function:

   noise_model(a,b, circuit):
   ``Given a circuit, it adds a pauli X with “a” probability and pauli Z with “b” probability ``
   Return circuit_with_noise

2. Code the quantum repetition code: https://errorcorrectionzoo.org/c/quantum_repetition. Test the code with the noise model and only X errors. Why does the method not work for Z errors?
3. Code the Shor code: https://errorcorrectionzoo.org/c/shor_nine. Test the code with your noise model.
4. Code the Hamming code: https://errorcorrectionzoo.org/c/hamming743. Test your code with your noise model.
5. What are the differences between the Shor and Hamming codes?
6. What challenges have you detected in the process of building the error-correcting codes?

Task 4 QSVM

Your objective is to design and evaluate quantum machine learning models for a binary classification problem using the Iris dataset.

Requirements

- ☐ Create at least two different circuit-based proposals, each with distinct architectures and layers.
- ☐ Clearly describe the design choices for each proposal (e.g., number of layers, type of parameterized gates, entanglement structure).
- ☐ Use the Iris dataset restricted to a binary classification task (selecting two classes).
- ☐ Apply appropriate classical preprocessing (e.g., normalization, dimensionality reduction, or feature selection).
- ☐ Explain the rationale behind the chosen preprocessing methods.
- ☐ Evaluate the expressibility of each circuit to identify its representational limits.
- ☐ Discuss how the architecture affects the ability of the circuit to represent complex decision boundaries.
- ☐ Compare their performance and analyze strengths and weaknesses.
- ☐ Provide reasoning based on expressibility, accuracy, and practical considerations (e.g., scalability, circuit depth, or noise resilience).

Deadline
2 weeks from when you've submitted your application in your timezone.

Once you have finished a screening task, please submit your GitHub repository containing the code to this google form: https://forms.gle/cHspLi26aZALFcyT7 -- other forms of submission will not be accepted!

If you have any questions - please add comments to this document, or ask it in the QOSF slack workspace (invitation_link) in the #mentorship-applicants channel. We will be updating this document with more details and/FAQ to avoid confusion, so make sure to check it before asking :)

Have a nice day!

QOSF team

FAQ

Q: Can we use any quantum libraries or are we restricted to a particular set of tools?

A: Feel free to use whatever you like, just make sure that the tool doesn't solve the whole problem for you.
Regarding the language of choice, Python is definitely the preferred one, since this is the language that most of the mentors use.
You can do the task first in the language of your preference and then translate it to Python if that's more convenient for you.

Q: I am applying as a member of a team. How many tasks do we submit?

A: Each member of a team must submit their own screening task. This will help us judge the skill level of each individual team member and help us pair folks up with the right mentor.

Q: How should I submit the solution?

A: All the materials for the submission should be inside a GitHub repository. Please do not send us any loose files as attachments or in any other format. Please submit your GitHub repository to this google form once you've finished: https://forms.gle/cHspLi26aZALFcyT7

Q: My team-mate wants to leave the team because he/she/they can't manage these along with exams. So will this affect our team status or anything like that?

A: Well, just let us know and you can continue as an individual/smaller team.

Q: Is it possible to make more than one task and send everything together?
A: Yes, you can. But you should specify which task you want to be evaluated. In other words, do it as an exercise but it does not affect your chances to enter the program.

Q: Can I please get the slack link. I think the link has expired?

A: try this: https://qosf.slack.com/archives/C019UEZRCM9
Another one to try:
https://join.slack.com/t/qosf/shared_invite/zt-bw59w8b9-WJ~k0~FAMHukTZov4AnLfA

Q: It is saying that my email has no account in the workspace. This is my first time trying to login. What should I do?

No idea, try this link perhaps:
https://join.slack.com/t/gosf/shared_invite/zt-2er4zd5p3-SLCQurkbQukt7vIiKHqlHg

Q: The last two slack links say that they are no longer active, while the first one shows the following error “doesn’t have an account on this workspace.”. What should be done?
A: Please reach out to gosf.mentorship@gmail.com in this case or if you have any other questions.