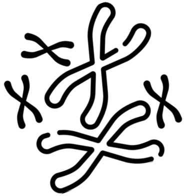
QHack 2023

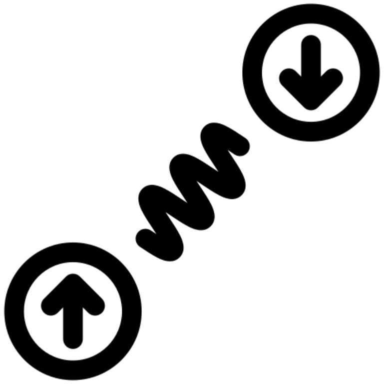
“Quantum Circuit Design using Genetic Algorithms”



Ashutosh Mishra | Taradutt Pattnaik | Shivnag Sista

Objective

To create interesting quantum states



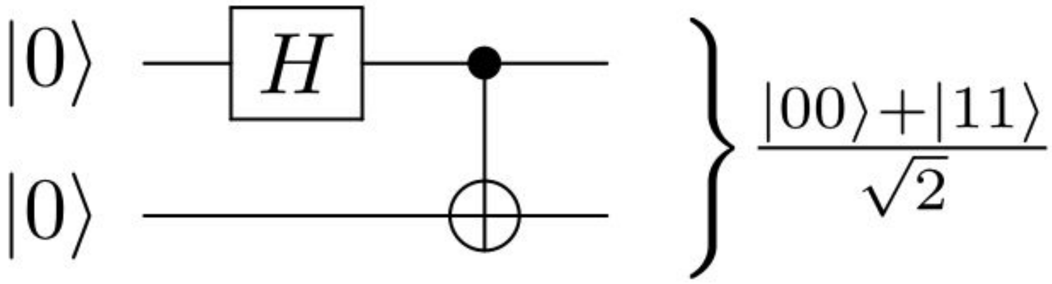
Quantum computing icons created by Vlad Szirka - Flaticon

Rationale

- **Universal quantum computation** requires the implementation of the gates such as the S gate and the T gate.
- These gates are usually implemented using **gate teleportation**, which require special states known as **magic states**.
- Several other quantum computing applications also need **entangled states**.

Preparing entangled quantum states

- We use quantum circuits to prepare such states.



- Coming up with these circuits is non-trivial.

- These quantum circuits were traditionally constructed manually, using intuition and experience.

- This is inefficient and tedious. The most intuitive circuits may not be optimized for circuit depth.

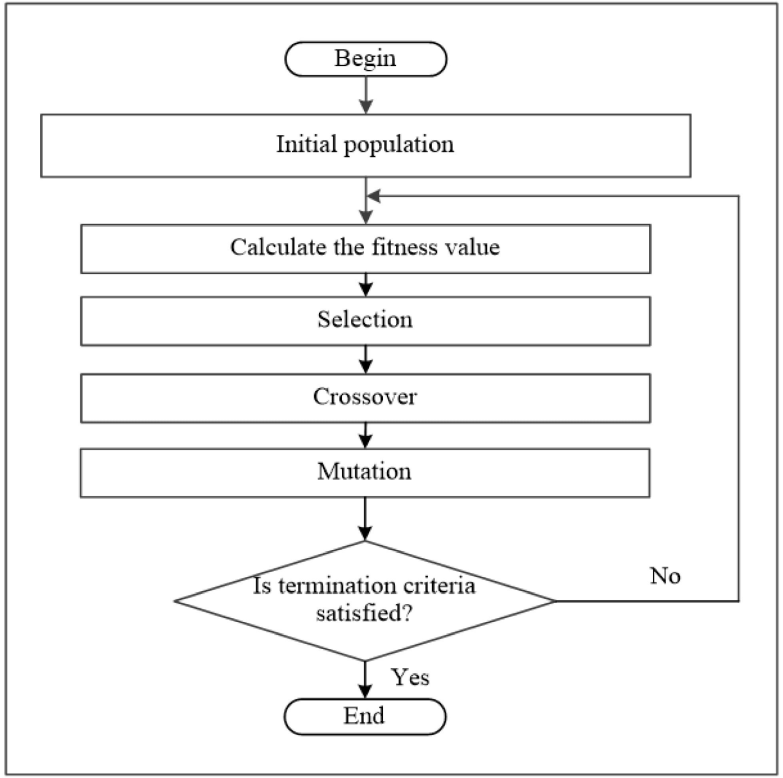
Enter Genetic Algorithms!

Optimization algorithms inspired by the biological process of natural selection.

Basic Strategy

- We start by creating a large **population** of candidate solutions to the problem, each solution being characterized by a set of parameters.
- A **fitness function** is used to find the best solutions of this population.
- The best solutions are used to create the next generation of solutions using the processes of **crossover** and **mutation**.
- Rinse and repeat until we get the desired level of fitness.

A Generic Genetic Algorithm



Albadr, Musatafa Abbas, et al. "Genetic algorithm based on natural selection theory for optimization problems." Symmetry 12.11 (2020): 1758.

GASP - A Genetic Algorithm for State Preparation

GASP – A Genetic Algorithm for State Preparation

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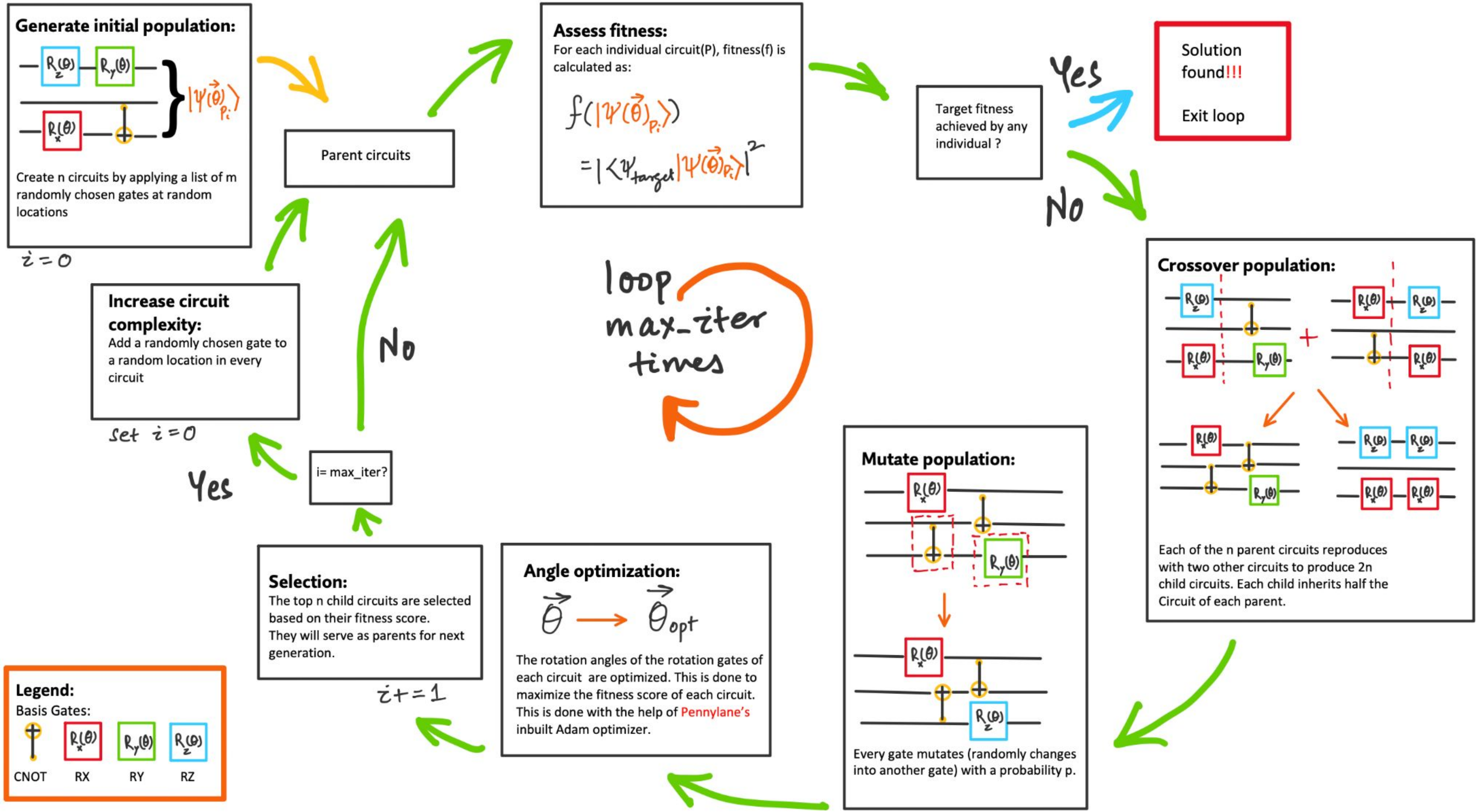
The efficient preparation of quantum states is an important step in the execution of many quantum algorithms. In the noisy intermediate-scale quantum (NISQ) computing era, this is a significant challenge given quantum resources are scarce and typically only low-depth quantum circuits can be implemented on physical devices. We present a genetic algorithm for state preparation (GASP) which generates relatively low-depth quantum circuits for initialising a quantum computer in a specified quantum state. The method uses a basis set of R_x, R_y, R_z, and CNOT gates and a genetic algorithm to systematically generate circuits to synthesize the target state to the required fidelity. GASP can produce more efficient circuits of a given accuracy with lower depth and gate counts than other methods. This variability of the required accuracy facilitates overall higher accuracy on implementation, as error accumulation in high-depth circuits can be avoided. We directly compare the method to the state initialisation technique based on an exact synthesis technique by implemented in IBM Qiskit simulated with noise and implemented on physical IBM Quantum devices. Results achieved by GASP outperform Qiskit's exact general circuit synthesis method on a variety of states such as Gaussian states and W-states, and consistently show the method reduces the number of gates required for the quantum circuits to generate these quantum states to the required accuracy.

Keywords: quantum computing, genetic algorithm, state preparation

Creevey, Floyd M., Charles D. Hill, and Lloyd CL Hollenberg. "GASP--A Genetic Algorithm for State Preparation." *arXiv preprint arXiv:2302.11141* (2023).

Genetic Algorithm for circuit design



Results

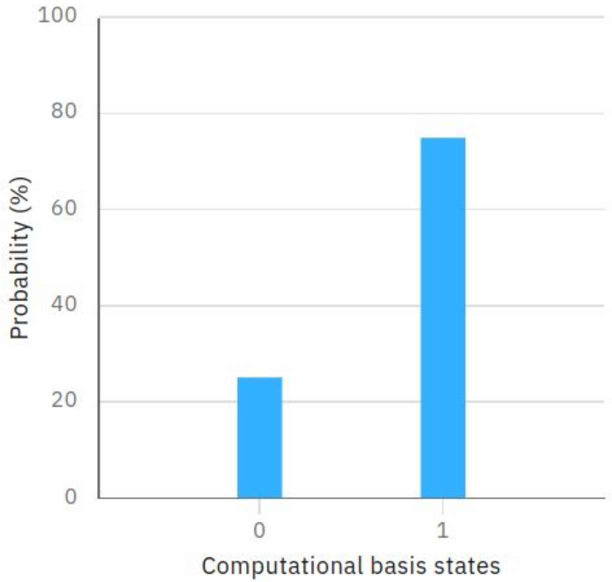
Single Qubit Magic state

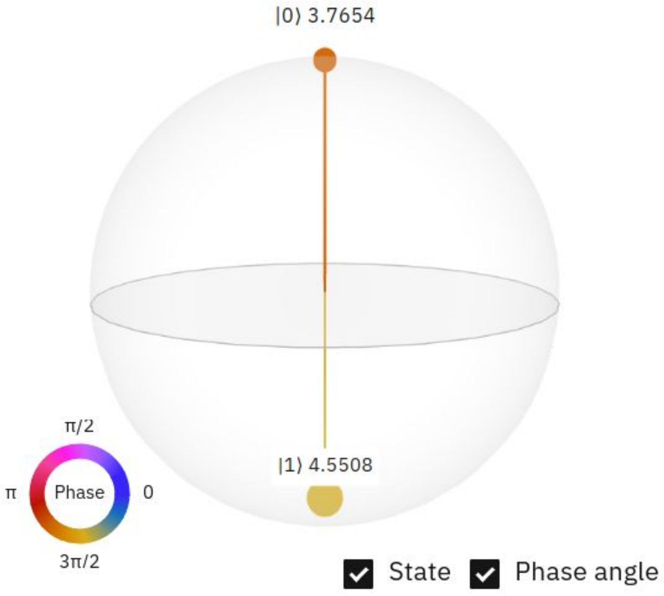
Target State: T-gate magic state

$$|T_0\rangle = cos(\beta)|0\rangle + e^{i\frac{\pi}{4}} sin(\beta)|1\rangle$$

Assuming $\beta = \frac{\pi}{3}$

Circuit proposed by GA to achieve target state:

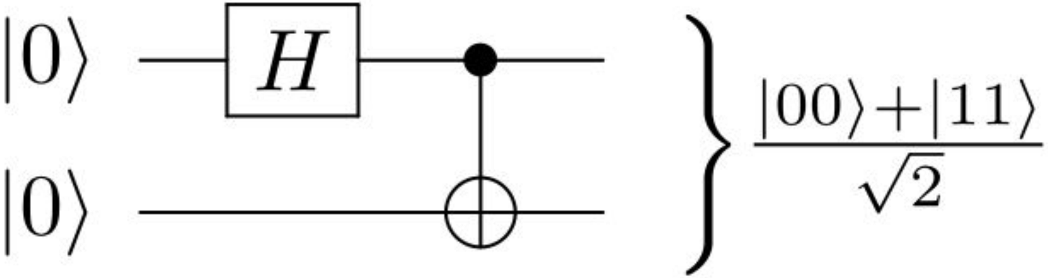




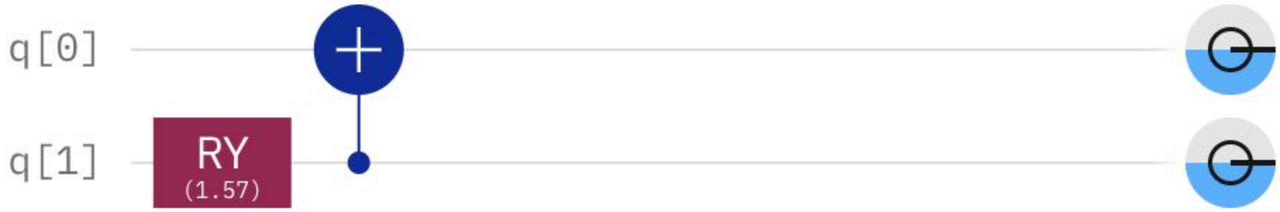
Two-Qubit Maximally Entangled states

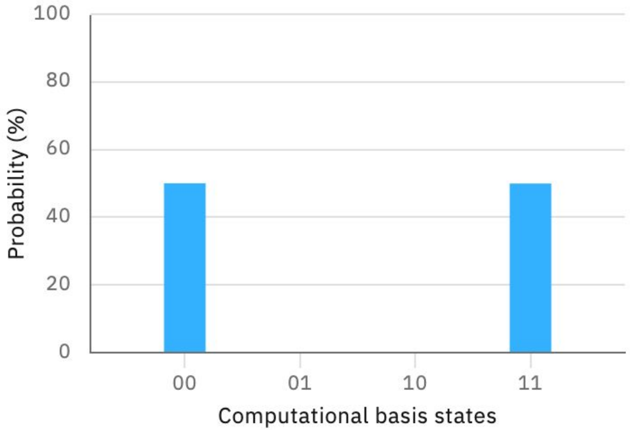
Target State: Bell state

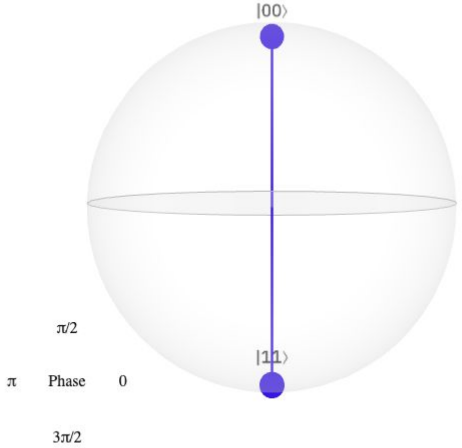
Standard circuit for Bell state:



Circuit proposed by GA to achieve target state:





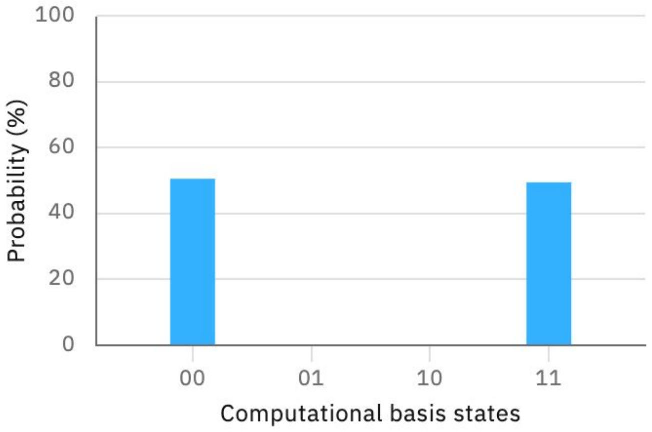


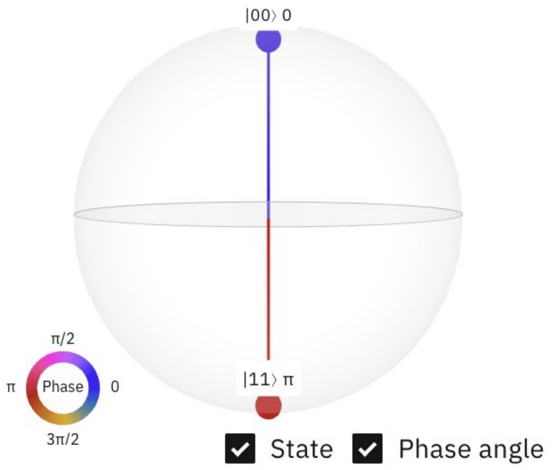
Target State: Another Bell State

$$\frac{(|00\rangle - |11\rangle)}{\sqrt{2}}$$

(There are 4 Bell states)

Circuit proposed by GA to achieve target state:





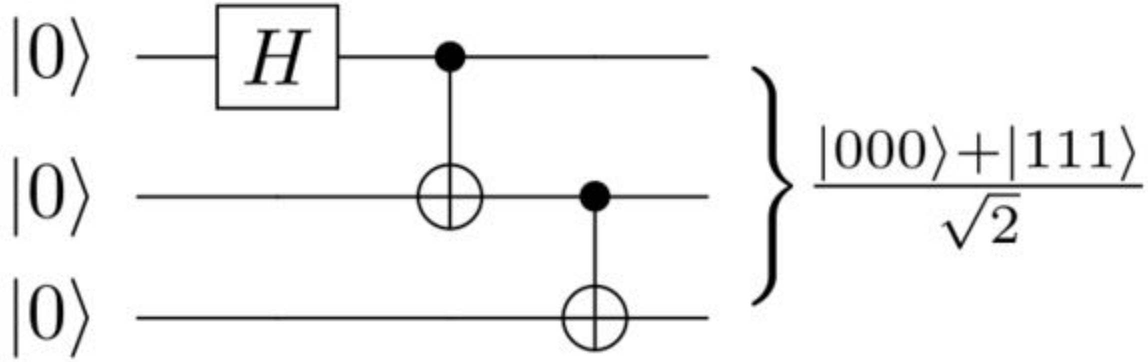
Three-Qubit Maximally Entangled states:

There are only two classes of maximally entangled states for 3 qubits - the GHZ state and the W state.

Dür, Wolfgang, Guifre Vidal, and J. Ignacio Cirac. "Three qubits can be entangled in two inequivalent ways." *Physical Review A* 62.6 (2000): 062314.

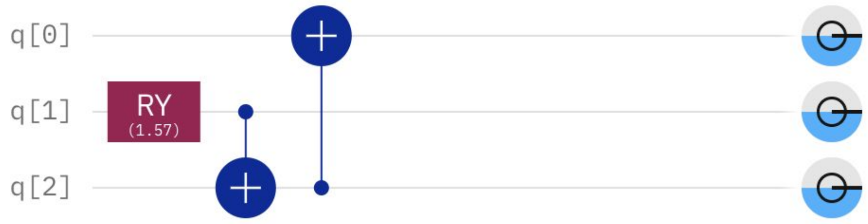
Target State: GHZ State

Standard circuit for 3-qubit GHZ state:

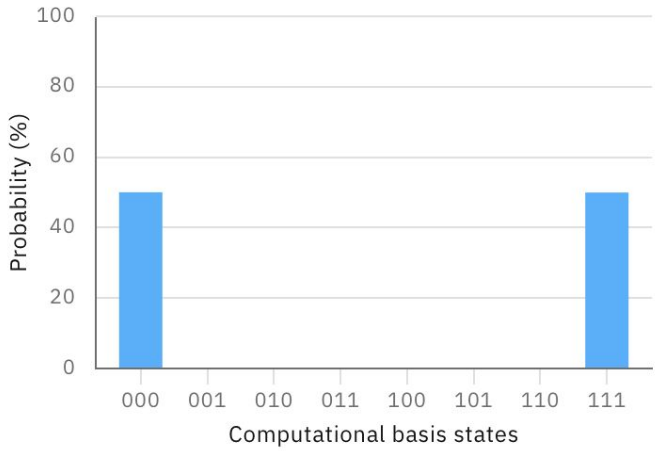


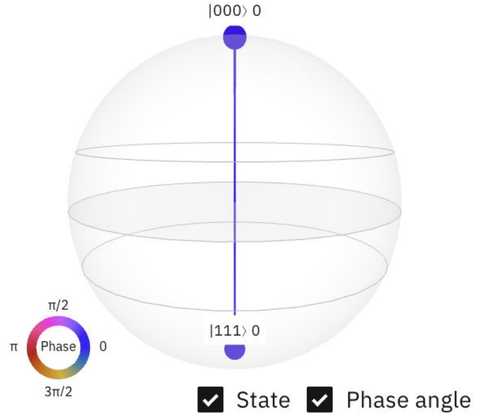
Circuits proposed by GA to achieve target state:

Proposed circuit 1:



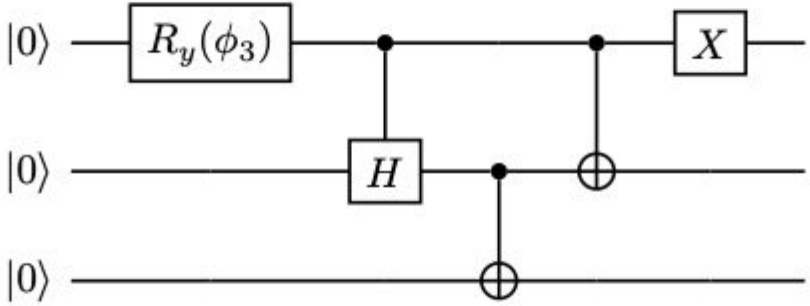
Proposed circuit 2:





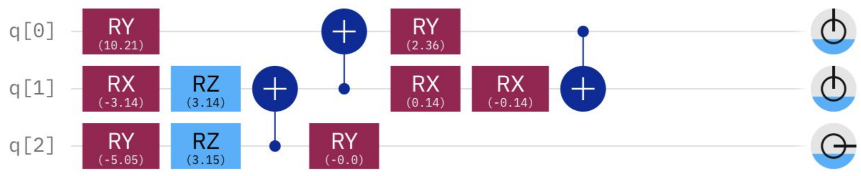
Target State:

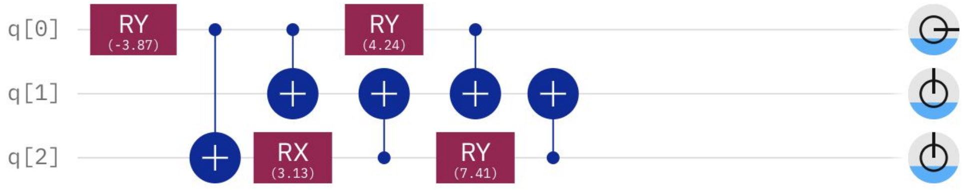
Standard circuit for 3-qubit W state:

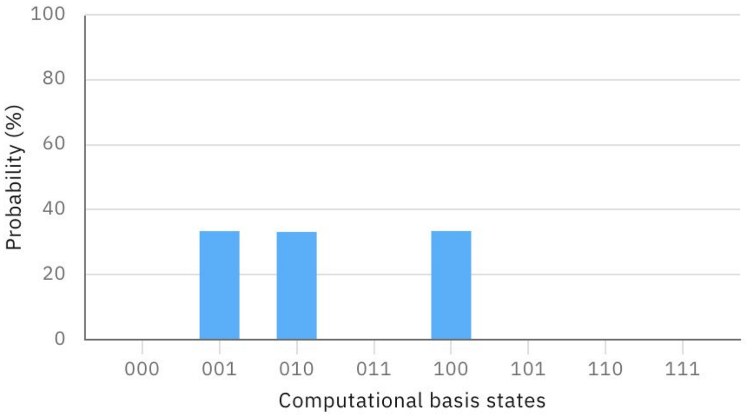


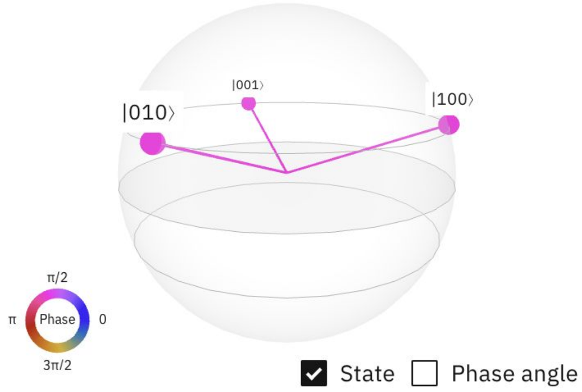
$$\frac{|001\rangle + |010\rangle + |100\rangle}{\sqrt{3}}$$

Circuits proposed by GA to achieve target state:



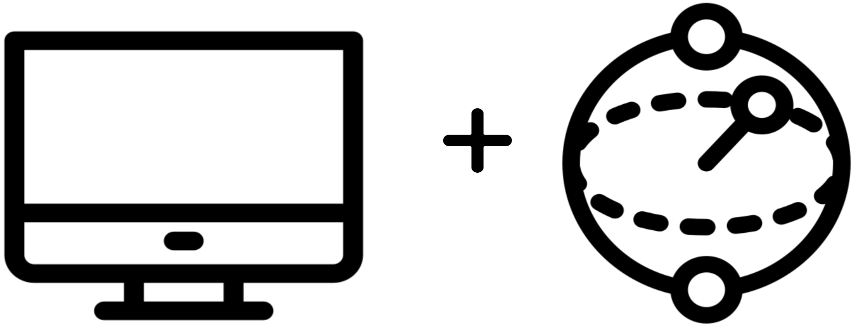






Hybrid Quantum classical Algorithm:

We used ideas from both classical and quantum computing to achieve our goal of state preparation.



*Pc monitor icons created by iconnut - Flaticon
*Plus icons created by srip - Flaticon
*Quantum bit icons created by Vlad Szirka - Flaticon

Future Directions

- Applying our approach to noisy quantum gates (relevant to the NISQ era).
- Examining the feasibility of the circuits designed by the algorithm.

References

[1] Our Jupyter notebook which has more detailed explanations.

[2] Creevey, Floyd M., Charles D. Hill, and Lloyd CL Hollenberg. "GASP--A Genetic Algorithm for State Preparation." arXiv preprint arXiv:2302.11141 (2023).

[3] Sünkel, Leo, et al. "GA4QCO: Genetic Algorithm for Quantum Circuit Optimization." arXiv preprint arXiv:2302.01303 (2023).