OPTIMAL CONTROL OF A NEUTRAL-ATOM QUANTUM PROCESSOR

Robust optimization of entangling gates on a neutral-atom quantum computer

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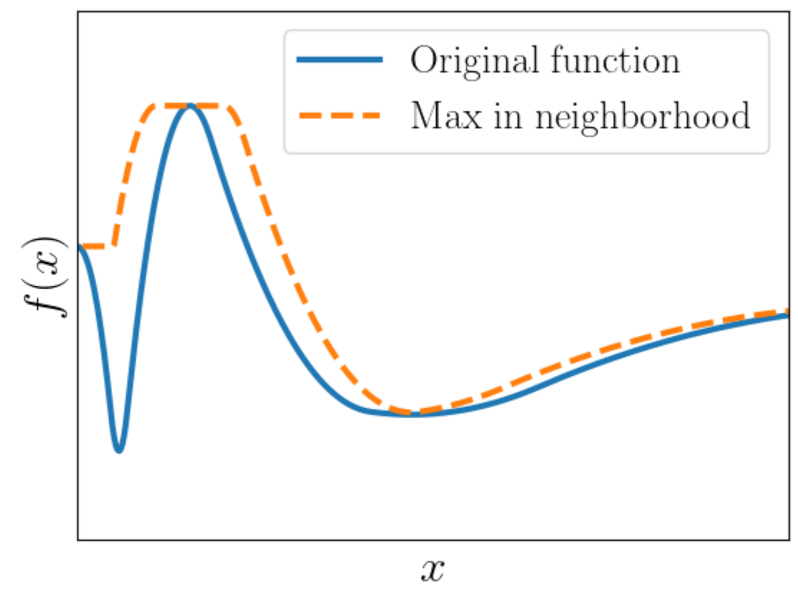
MOTIVATION

- Quantum computers hold promise to solve numerous challenges faced in contemporary computing
- However, they are sensitive to noise as they operate at incredibly fine scales
- This motivates the design of gates which are the least sensitive to perturbations in experimental error
- The gate examined in this work was a CZ gate recently proposed for our computer [1]
- CZ gates are used to entangle qubits, which is a sensitive operation yet important for quantum computation

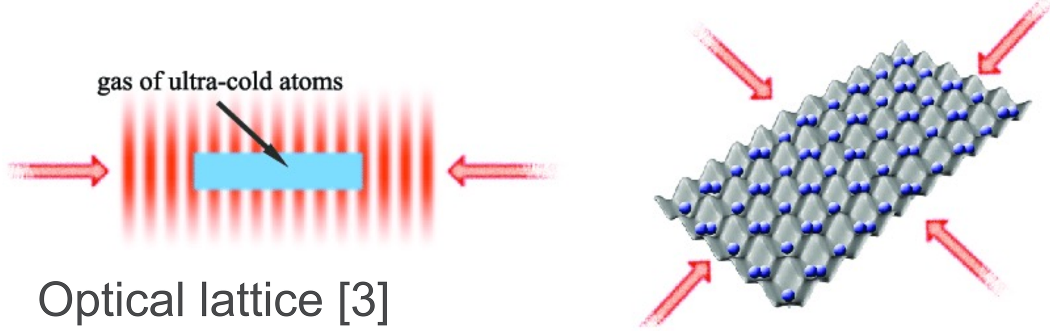
ROBUST OBJECTIVE

- Along with optimizing the state fidelity itself, we optimized the worst-case state fidelity with respect to perturbations in the input pulse
- This allows us to find high-fidelity points stable against noise found in experiment

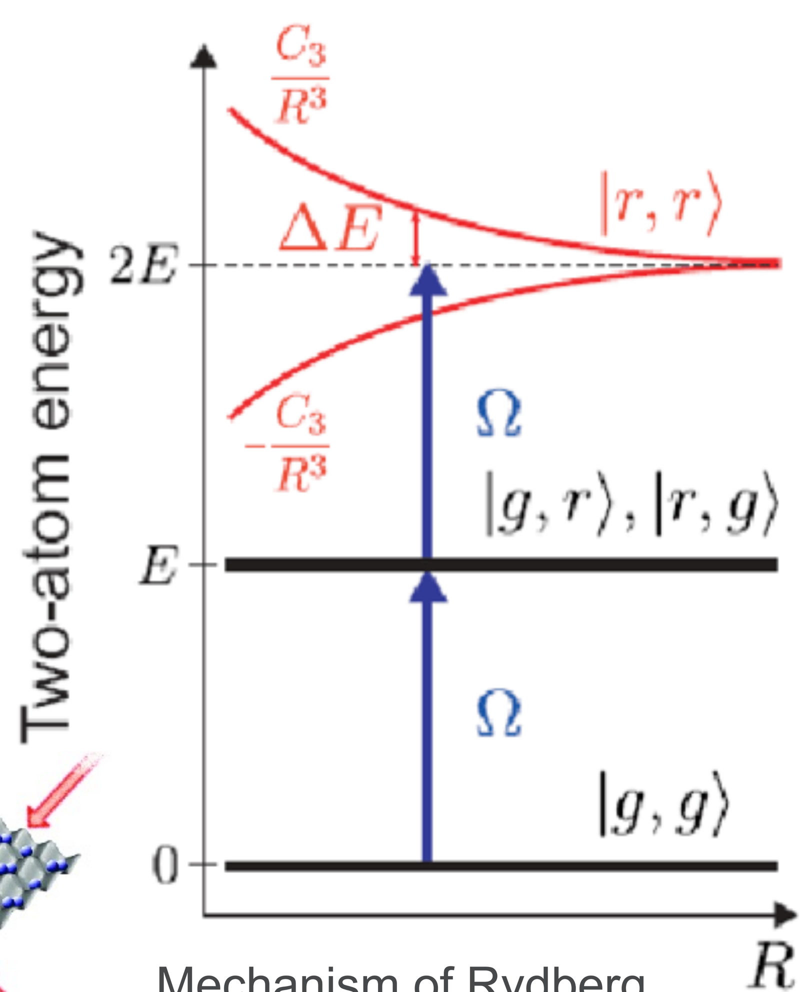


PHYSICS

- We encode data in hyperfine levels of cesium atoms, which are trapped in an optical lattice
- Gates are implemented using lasers, which drive transitions between energies through stimulated absorption and emission
- To entangle atoms, we employ Rydberg blockage
- Atoms in the Rydberg state change the energy levels of surrounding atoms, which may be exploited to entangle atoms



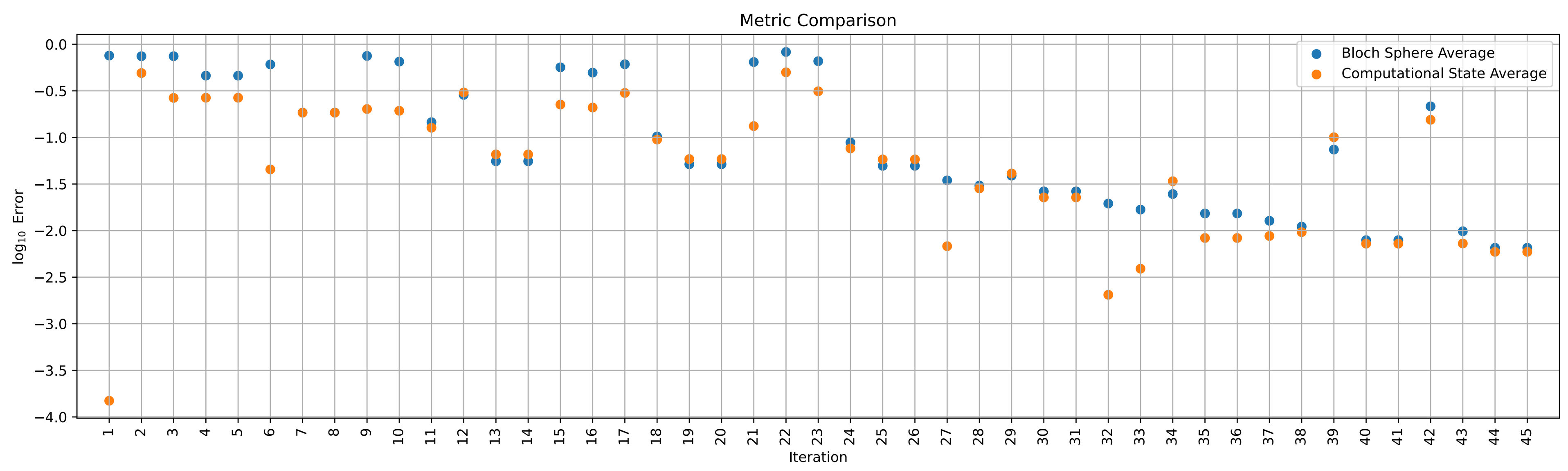
Optical lattice [3]

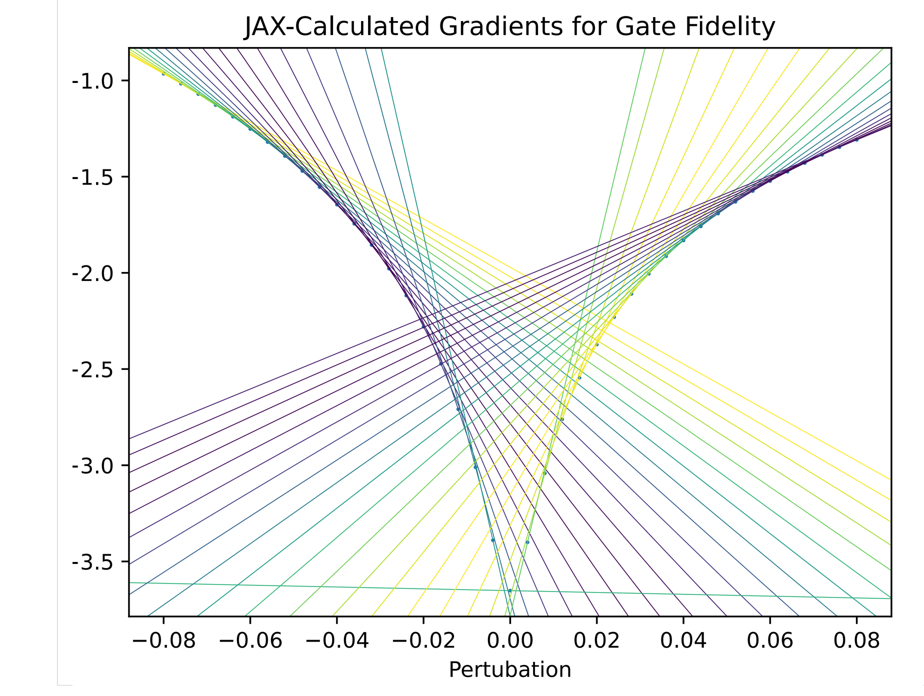


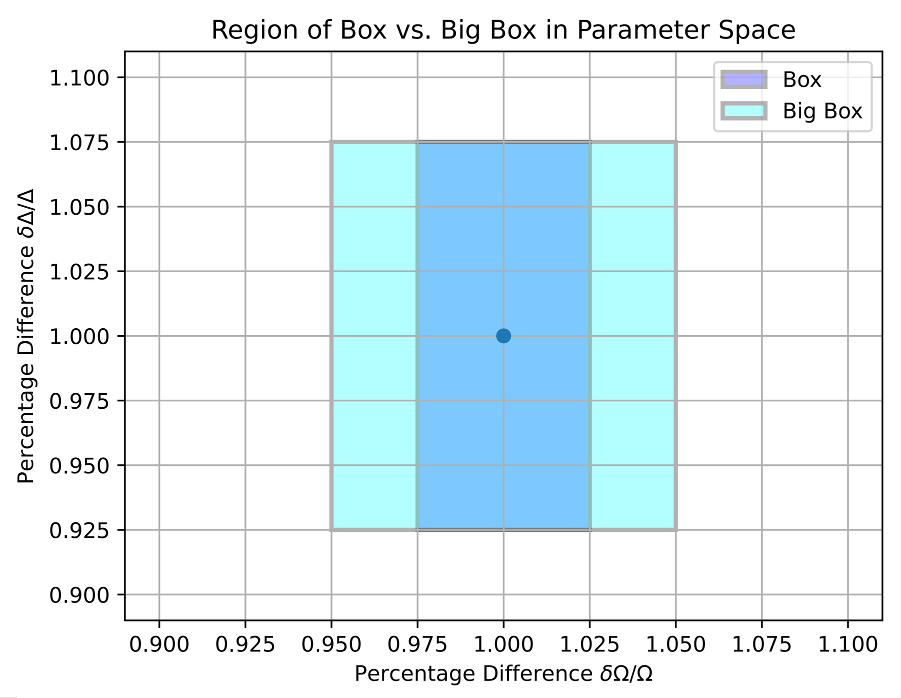
Mechanism of Rydberg blockage [2]

METHODS

- We used the average gate fidelity over all input states as a metric
- Two different robust objectives corresponding to different parameters errors (Box & Big Box) were simulated
  - Box is the worst-case for a 5% error for typically inaccurate parameters & 1% error for all others, Big Box employs a 5% error for all parameters
- We used JAX to obtain gradients for optimization using backpropagation
- We used the NLOpt library for optimization

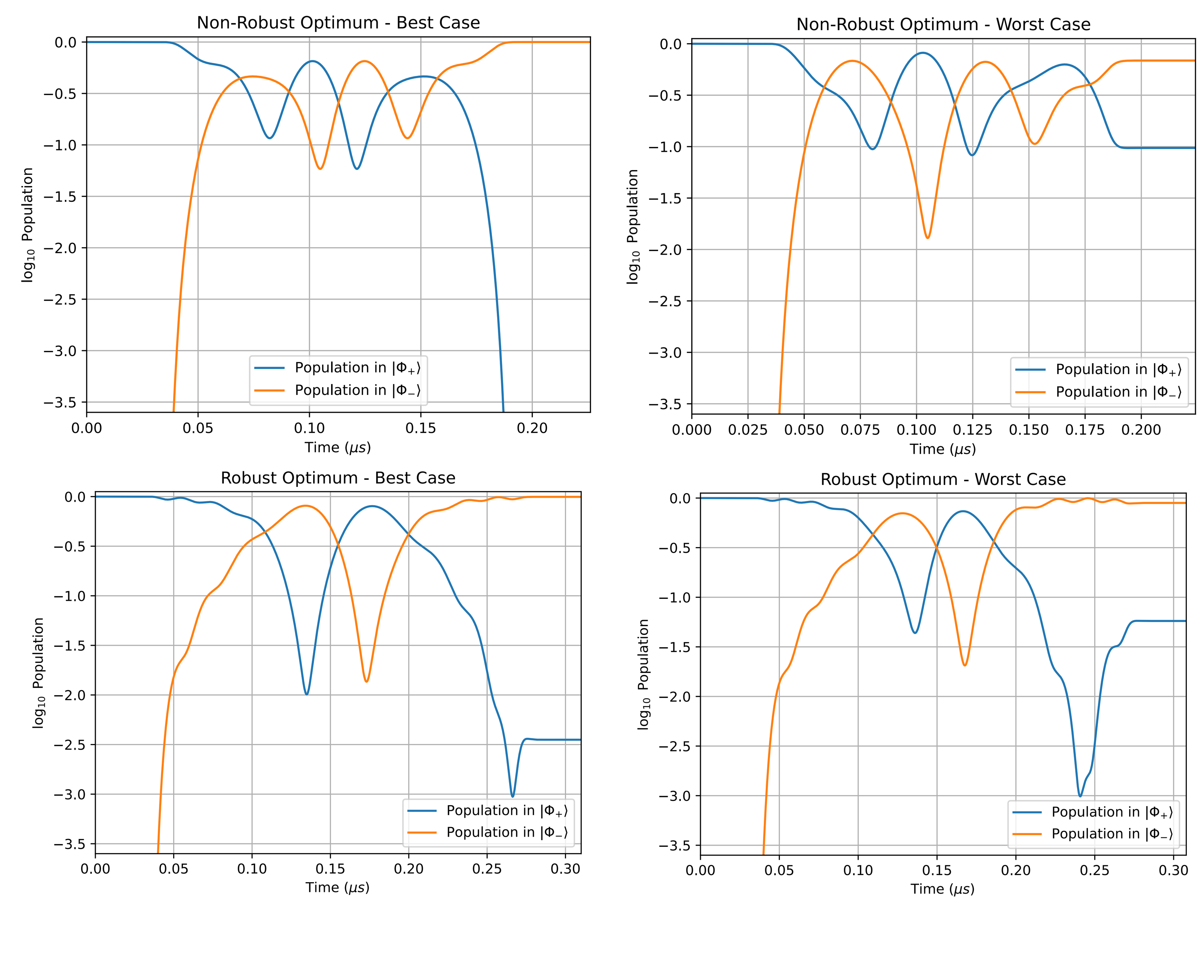






RESULTS

- The optimum parameters using the Box metric gave a robust fidelity of 0.92, while the optimum parameters using Big Box gave a robust fidelity of 0.85
- Qualitative differences in qubit population were observed in the non-robust and robust gates



CONCLUSIONS

- Using the proposed gate in [1], we are able to get a robust fidelity of >0.9 with respect to errors of up to 5% in typically sensitive parameters
- Our non-robust and robust optima show significant difference in both quantitative and qualitative behavior
- The average gate fidelity seems to be well suited for this problem, as it encapsulates data from other metrics used

NEXT STEPS

- We plan on investigating reasoning for certain pulses to be more robust
- We also hope to extend our work to 4-5 qubit gates which have been proposed to work on a neutral-atom quantum computer
- In addition, we intend on expanding our model to include different types of noises
- These sources could include a finite-temperature qubit or crosstalk interactions between qubits on a larger array

REFERENCES

- [1]: C. Poole, T. M. Graham, M. A. Perlin, M. Otten, & M. Saffman. (2024). Architecture for fast implementation of qLDPC codes with optimized Rydberg gates.
- [2]: Pillet, P., Vogt, T., Viteau, M., Chotia, A., Zhao, J., Comparat, D., Gallagher, T., Tate, D., Gaëtan, A., Miroshnychenko, Y., Wilk, T., Browaeys, A., & Grangier, P. (2009). Controllable interactions between Rydberg atoms and ultracold plasma. *Journal of Physics: Conference Series, 194, 012066.*
- [3]: Bietenholz, W., Laflamme, C., Evans, W., Dalmonte, M., Gerber, U., Mejía-Díaz, H., Wiese, U.J., & Zoller, P. (2016). Proposal for the Quantum Simulation of the CP(2) Model on Optical Lattices.