Increasing the Efficiency of Neutral Atoms

Reducing Qubit Waste from Measurement-related Ejections

Jason Ludmir, Tirthak Patel (Advisor)
Rice University

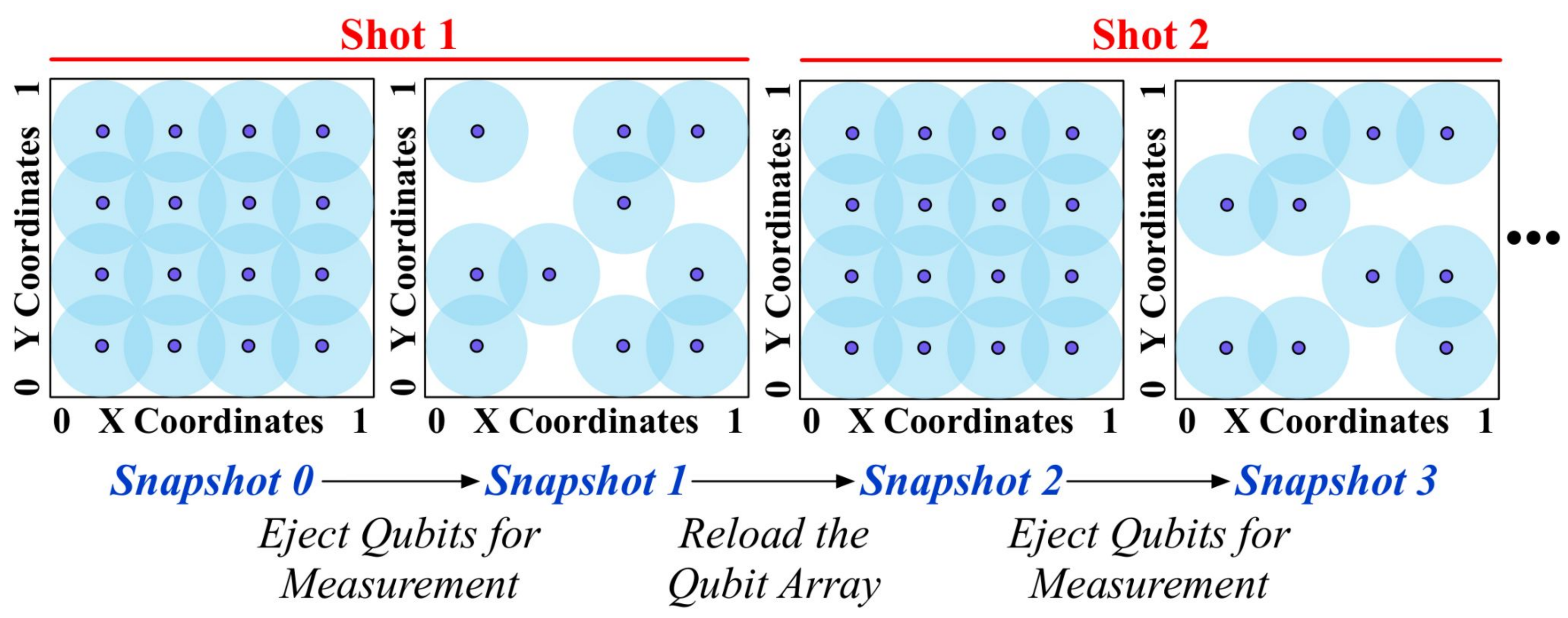
Introduction

Background and Motivation

- Quantum computing offers speedups for HPC applications such as cryptography, optimization, ML and molecular simulation
- Neutral atom quantum computers offer customizable qubit topologies, lower decoherence rates, and improved scalability compared to other quantum technologies

The Problem: Measurements require physically ejecting atoms in the $|1\rangle$ state, leading to substantial time waste in reloading arrays

The Challenge: To reduce this waste, the primary challenge is to identify and address qubits that are likely to be measured in the $|1\rangle$ state before the quantum circuit is fully executed

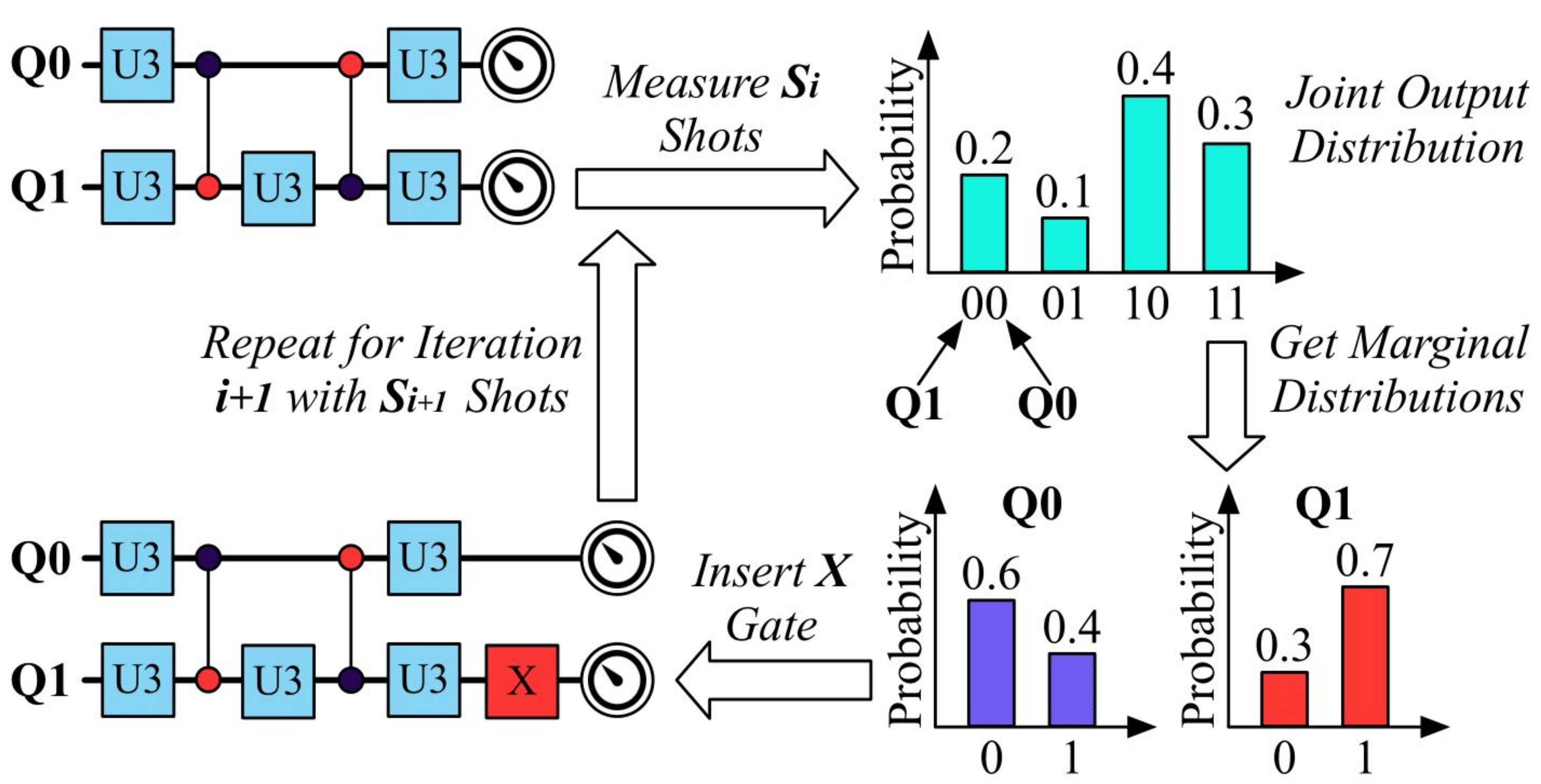


Our Solution: Leverage the probabilistic nature of quantum programs to reduce qubit ejections and atom array reloads

Our Approach: Our technique flips qubits likely to be in the $|1\rangle$ state before measurement by using adaptive scheduling, and efficiently moves atoms to refill ejected positions, thereby reducing qubit ejections and minimizing atom array reloads

Design & Implementation

Workflow: Reducing Atom Ejections via Output Distribution



Workflow: To reduce qubit ejections, we first execute and measure the output after a batch of shots. Using the joint output distribution, we derive marginal distributions for each qubit. Based on these probabilities, we insert X gates (also known as bit-flip gates) before measurement for qubits likely to be in the $|1\rangle$ state. This process is repeated for subsequent iterations.

How often are output probabilities recomputed?

- Constant, proportional, linear, quadratic, and entropic schedules
- Different schedules allow for optimization of different circuit types

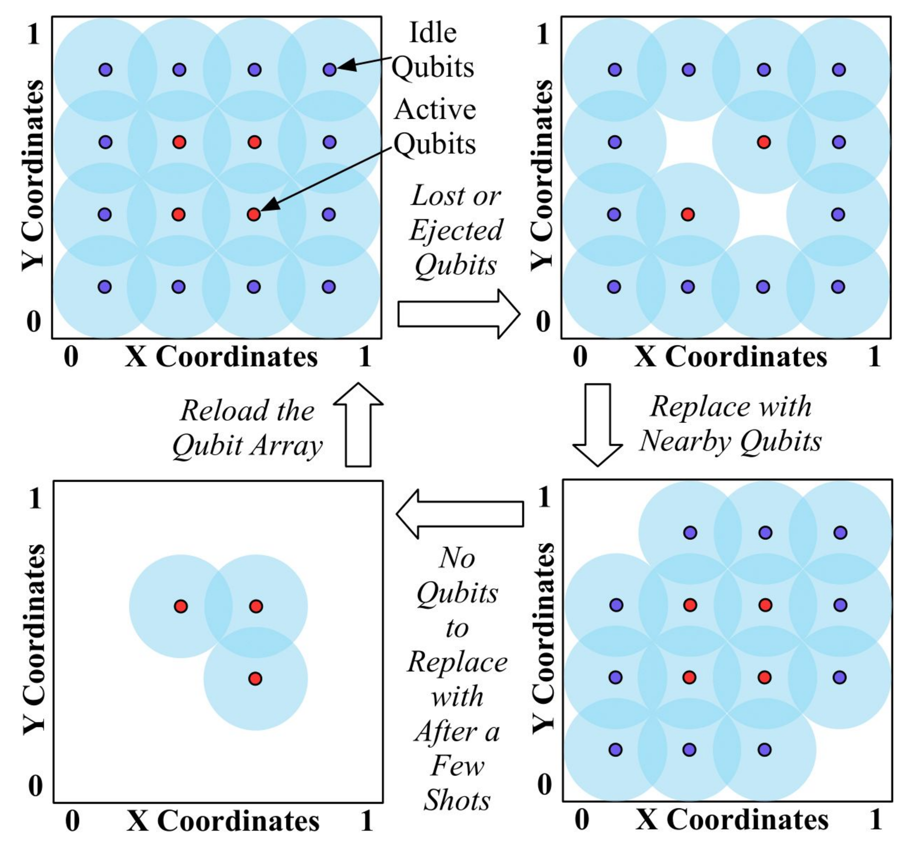
How does it minimize array reloads?

- Maps circuit qubits to center of atom array for efficient refilling
- Moves nearby available atoms to fill ejected positions

Experimental Details

Methodology:

- 525 random circuits (16-30 qubits, 4-15 depth)
- 12 real algorithms from the QASMBench suite
- 1024 shots per circuit run
- IBM's Qiskit library with QASM Simulator backend
- Comparison with Oracle (best-case) and No Policy (baseline) scenarios

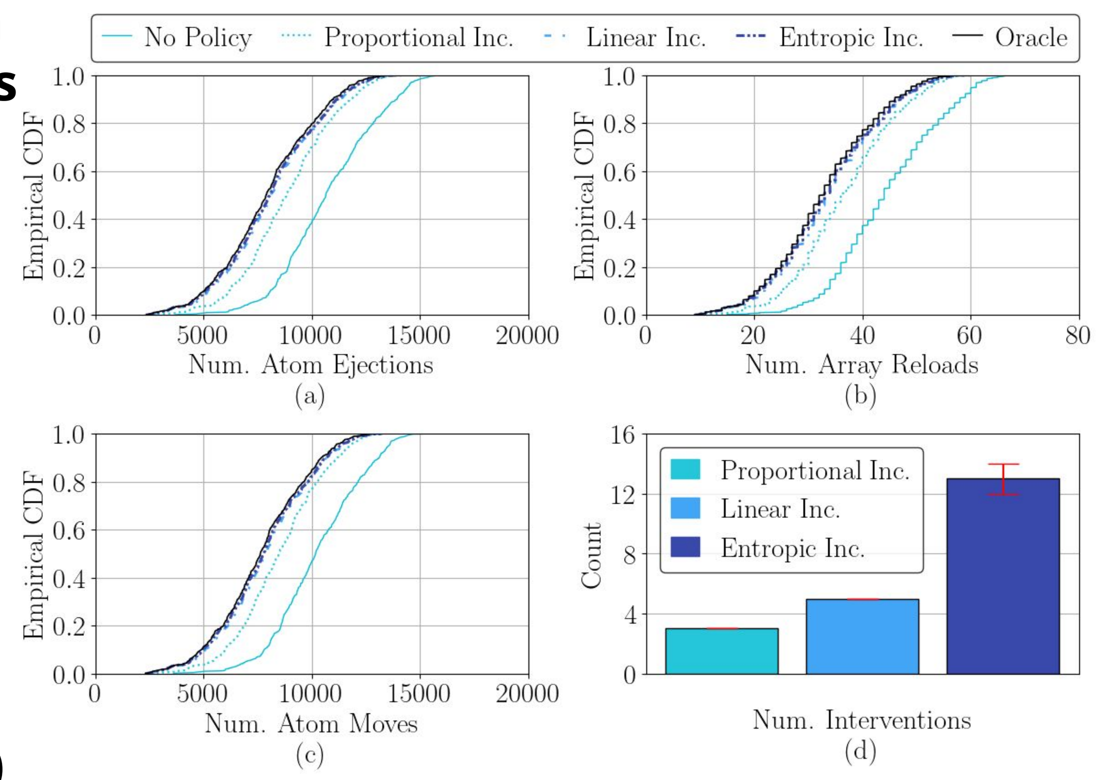


Atom Array Simulation:

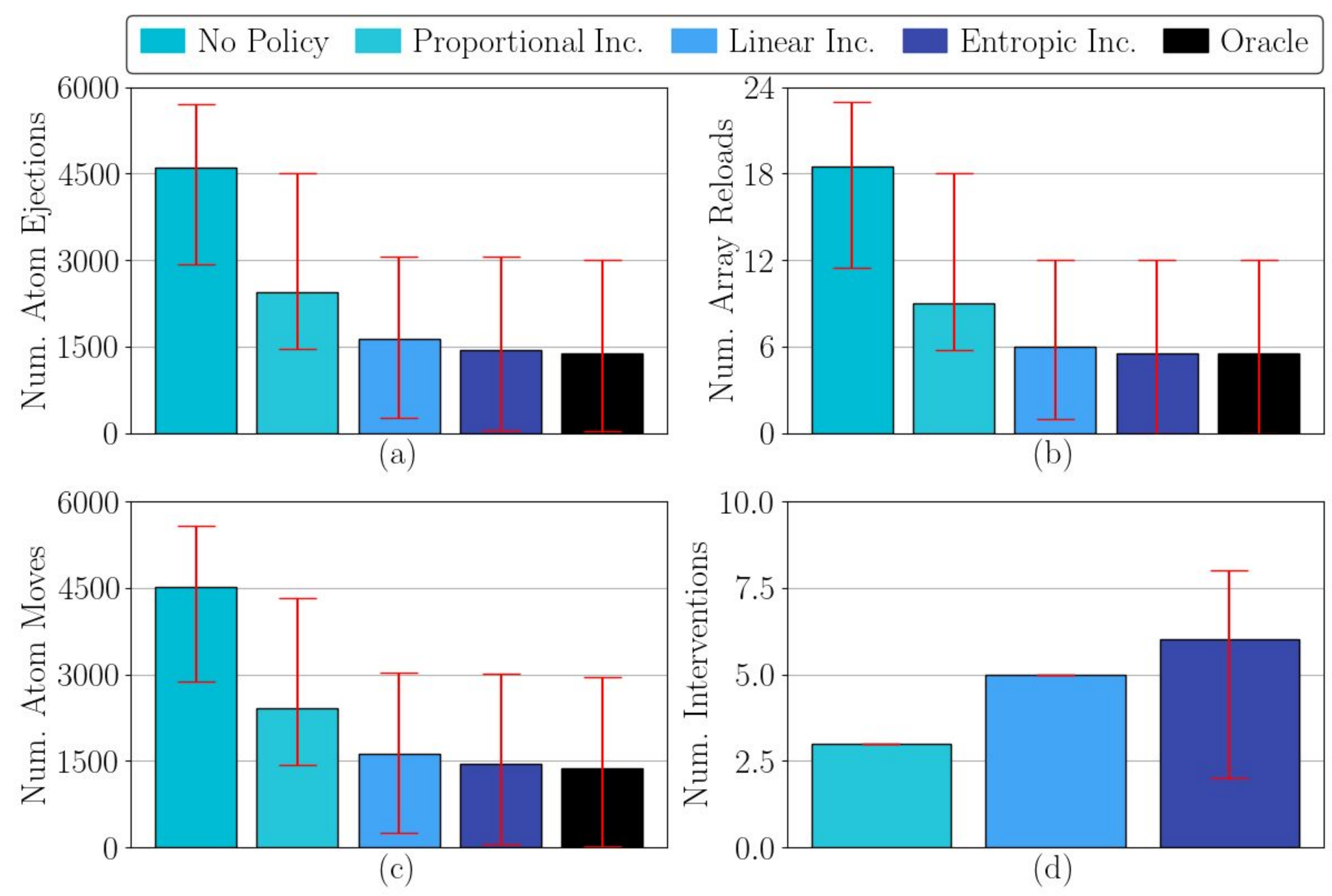
- 256 atom array, mimicking the QuEra Aquila system (AWS cloud)
- Active qubits mapped to the atoms at the center of the atom array
- Idle qubits surround the active region of quantum computation
- Ejected qubits are replaced by nearby idle qubits (as shown above)
- Full array reload when insufficient idle qubits remain

Results & Analysis

We reduce the median num. of atom ejections & reloads by 25% and atom moves by 24% compared to the baseline for random circuits



Entropic intervention technique performs best, nearly matching the performance of the Oracle – lower is better for all except subplot (d)



Our technique achieves better results on real algorithms, with 53% reduction in median atom ejections, 54% reduction in array reloads, and 53% reduction in atom moves

Discussion and Conclusion

- Effectiveness increases with more structured quantum algorithms with realistic characteristics
- Entropic intervention efficiently balances performance gains with the computational overhead of analysis and updates
- Significant reductions in atom ejections translate to substantial time savings in neutral atom quantum computers