ARGONNE **LEADERSHIP COMPUTING** FACILITY

Full State Quantum Circuit Simulation by Using Lossy Data Compression

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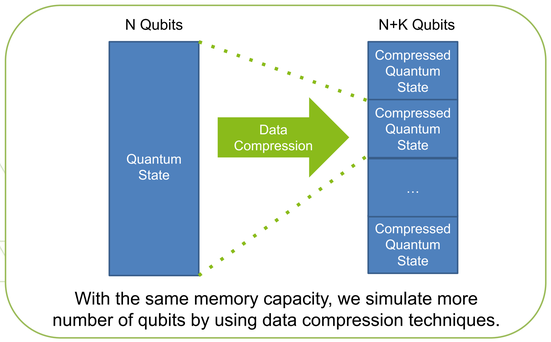
Abstract

To evaluate, validate, and refine the design of a new quantum algorithm or a quantum computer, researchers and developers need methods to assess their correctness and fidelity. This requires the capability of simulation for full quantum state amplitudes. However, the number of quantum state amplitudes increases exponentially with the number of qubits, leading the memory requirement growing exponentially. In this work, we present our technique to simulate more qubits than previously reported by using lossy data compression. Our empirical data suggests that we can simulate full state quantum circuits up to 63 qubits with 0.8 petabytes memory.

Objective

System	Memory (PB)	Max Qubits
TACC Stampede	0.192	43
Titan	0.71	45
Theta	0.8	45
K computer	1.4	46
Exascale	4-10	48-49



With the same memory capacity, we simulate more number of qubits by using data compression techniques.

Introduction

Quantum State:

- Given n qubits, the size of the state vector is 2^n complex amplitudes.
- $|\Psi\rangle = a_0 |000\ldots000\rangle + a_1 |000\ldots001\rangle + \ldots + a_{2^n} |111\ldots111\rangle$

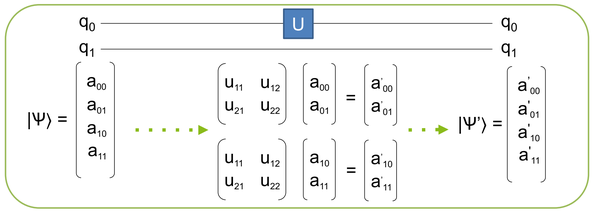
Quantum Gates: H X Y Z S T +

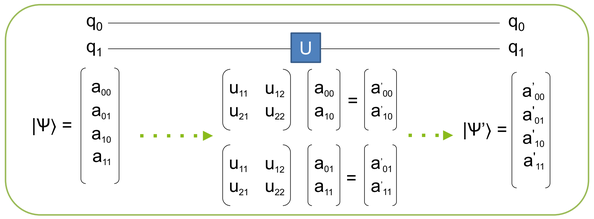
- Each quantum gate is expressed by a corresponding matrix.
- Applying a quantum gate to the quantum state is equivalent to multiplying the state vector by the corresponding matrix.

Quantum Circuits Simulation

Intel-QS: Distributed High Performance Quantum Computing Simulator

- Using MPI (message-passing-interface) protocols to store and manipulate the quantum state for both intra- and inter-node operations.
- Full state amplitude-vector update
- Capable of high depth quantum circuits simulation





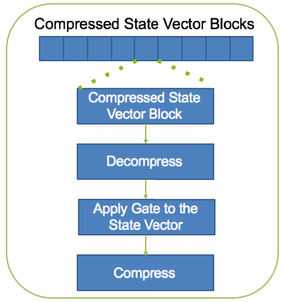
Data Compression in Quantum Circuits Simulation

SZ: Error-bounded Lossy Compressor for HPC Data

- Support parallel in-situ compression
- MPI/openMP

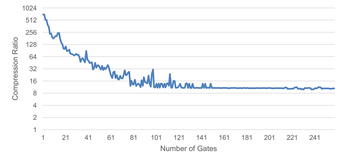
Simulation:

- The full quantum state vector is divided into several state vector blocks.
- All state vector blocks are compressed and stored in memory.
- Each block is decompressed to perform the computation.
- The block is compressed again after the computation.
- Each state vector block is decompressed and compressed for each gate operation.



Results

Benchmark 1: QAOA - 17 Qubits and 260 Gates

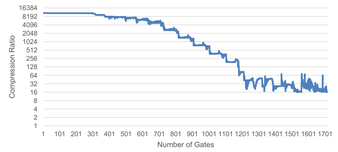


N+3 Qubits

Fidelity: 92.5%

Performance Overhead: 64%

Benchmark 2: QFT - 26 Qubits and 1710 Gates

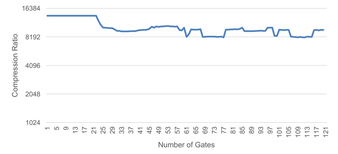


N+4 Qubits

Fidelity: 99.9%

Performance Overhead: 15x

Benchmark 3: Grover's Search - 17 Qubits and 120 Gates

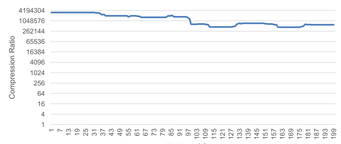


N+13 Qubits

Fidelity: 99.9%

Performance Overhead: 90%

Benchmark 4: Grover's Search - 30 Qubits and 199 Gates



N+18 Qubits

Fidelity: 99.9%

Performance Overhead: 19x

Conclusion

- We present a full state quantum circuits simulation technique to simulate more qubits than previously reported by using lossy data compression.
- Our approach compress the state vector to reduce the memory requirement, so the we can simulate a larger quantum system with the same memory capacity.

Future Work

- Analyzing effect of compression errors and relationship to real physical noise
- Integration with other approximate simulation techniques
- Evaluating different compression algorithms for quantum state

References

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Acknowledgments

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