Q-GPU: A Recipe of Optimizations for Quantum Circuit Simulation Using GPUs

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Motivation

- Quantum supremacy
- Limited system size and access in NISQ era.
- A robust and efficient quantum circuit simulator is necessary.

Project Description

- Systematically investigate the performance deficiencies in modern quantum circuit simulation (QCS).
- Propose Q-GPU, a framework that packed with sophisticated optimizations to fuel QCS using GPUs.
- Introduce gate runahead execution to parallelize gate operations in QCS.

Context

- Observation: slow simulation and poor scalability of public quantum circuit simulators.
- Q-GPU features (Fig.1)
  - proactive state amplitude transfer,
  - zero state amplitude pruning,
  - delayed qubit involvement,
  - lossless non-zero state amplitude compression.
- Enlarge Runahead potential by:
  - gate reordering
  - gate transforming
  - gate chain scheduling on gate position sensitivity

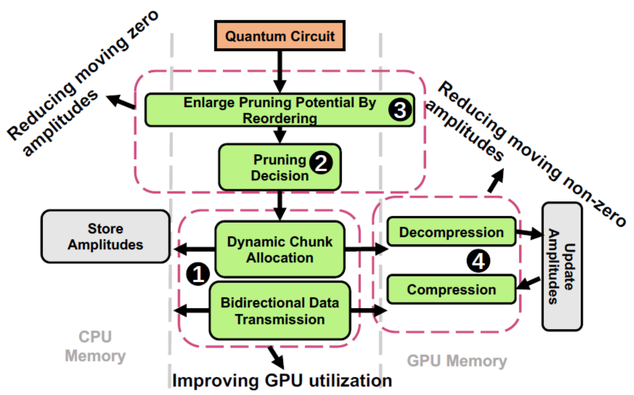

Fig 1: High level overview of Q-GPU.

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Towards large-scale quantum circuit simulation (QCS) via systematic investigation and optimization.

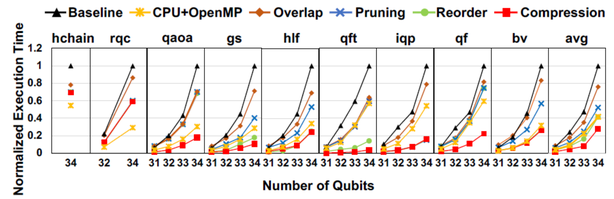

Figure 2: Normalized execution time for circuits with different number of qubits (the lower the better).

Project Deliverables

- Develop a toolset to facilitate quantum-related research in NISQ era.
- Q-GPU significantly reduces the execution time of QCS across all the circuits, specifically for the largest number of qubits (Fig.2)
- Runahead work also introduce significant speedup.

Potential Impact

- Efficient and effective practical quantum algorithm development on quantum simulator.
- Quantum programming interfaces, compilers, and runtime management.
- Quantum computer architecture design exploration including both quantum device architecture as well as the interaction between quantum device and the classical counterparts.

References and/or Acknowledgements

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