Synthesis on Atom Computation

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Quick Review

- Neutral atom controlled by laser lattice (stationary) and laser tweezers (move)
- Single qubit gate $U3 : (\Omega\tau \cos\varphi, \Omega\tau \sin\varphi, \delta\tau)$
- Multi-qubit gate $C\mathcal{Z} : 2|gg\rangle\langle gg| - I$

Paper Call Back

- Setup (the constraints it considered)
- Optimize goal (the cost it wants to reduce)
- Methods (how it finishes)

Outline

1. Decomposing and Routing Quantum Circuits Under Constraints for Neutral Atom Architectures

2. Compiling Quantum Circuits for Dynamically Field-Programmable Neutral Atoms Array Processors
FPQA-C: A Compilation Framework for Field Programmable Qubit Array

3. Discussion

Setup

- *StandardGateSet*: $\{U_3, CZ\}$
- Existing hardware does not support local addressing for all qubit rotations:
  - Local CZ
  - Local $R_Z(\lambda), (0, 0, \frac{\lambda}{2})$
  - Global $GR(\theta, \phi), (\frac{\theta}{2}\cos\phi, \frac{\theta}{2}\sin\phi, 0)$
- Atom movement

Optimization Goal

The primary optimization goal is to minimize:

- Circuit duration

Methods, Decomposition Techniques

$U3(\theta, \phi, \lambda) = RZ(\phi)RY(\theta)RZ(\lambda)$:

- $RY(\theta) = GR(\frac{-\pi}{2}, 0)RZ(\theta)GR(\frac{\pi}{2}, 0)$
- $RY(\theta) = Rv(\pi, \frac{\theta}{2})RZ(-\pi)$
- $Rv(\xi, \omega) = GR(\omega, \frac{\pi}{2})RZ(\xi)GR(-\omega, \frac{\pi}{2})$

Methods, Routing Algorithms

- Map

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Setup (FPQA)

- Gateset:
  - Global CZ
  - Local $U3$
- Optical traps are configured in 2D arrays.
- Two-qubit entangling gates require qubits to be within a certain proximity without interfering with others.
- Constraints of physical movement of traps, ensuring each solution step complies with the DPQA constraints and remains executable.

Constraints in the Greedy Method

- **DPQA Architectural Constraints**:
  - Adhere to movement and interaction rules specific to DPQA.
  - Maintain the logical sequence of gate operations.
- **Minimum Gates Threshold ('M')**:
  - Strive to achieve at least 'M' gates per stage, where 'M' is dynamically adjusted based on solvability.
- **SMT Solver Integration**:
  - Use an SMT solver to find feasible solutions that maximize gate execution while respecting the constraints.

SMT Solver Role in the Greedy Method

- **Input**: Reduced and simplified problem instances as the complexity is peeled off.
- **Output**: Feasible configurations that allow the maximum number of gates ('M') to be executed per stage.
- **Dynamic Adjustment**: Modifies 'M' based on the ease or difficulty of finding a solution, optimizing the balance between speed and completeness of the solution.

Transition to Optimal Compilation

- **Criterion for Transition**: Shifts to the optimal SMT-based approach when a significant portion of the problem has been resolved or when only a small percentage of gates remains.
- **Rationale**: Ensures that the final solution is both efficient and adheres strictly to all operational constraints.

Conclusion

The integration of the SMT solver within the Greedy Method in this hybrid approach allows for a pragmatic reduction of quantum circuit complexity, setting the stage for a detailed and optimal final compilation using SMT.

Methods (FPQA)

- Qubit-Array Mapper:
  - K-cut problem aiming to maximize the summation of edge weights crossing different partitions
- Qubit-Atom Mapper:
  - SLM Array: Load balance mapping
  - AOD Array: Alignment AOD mapping
- High-Parallelism Router:
  - U3 gate
  - Check constraint

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Discussion

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