基于 TDD 的量子模型检测中的可达性分析

硕士中期报告

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Credit Requirements

Credit Requirement Summary:

Public Compulsory Courses: 7 credits
Public Elective Courses: Minimum 2 credits
Major Degree Courses: Minimum 12 credits
Total Credit Requirement: Minimum 30 credits

Completed Credits:

Public Compulsory Courses: 7 credits
Public Elective Courses: 8 credits
Major Degree Courses: 18 credits
Total Credits Earned: 35 credits

Research Requirements

Publication Requirements:

Required to be among the top 3 authors on a paper in CCF-A/B category.

Completed Submissions:

ICCAD 2023 (CCF-B):

Review Outcome: Rejected

Reviewer Scores: 2, 4, 4

DAC 2024 (CCF-A):

Current Status: Under Review

Expected Feedback Date: On or before February 26, 2024

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Title: 基于 TDD 的量子模型检测中的可达性分析

Summary:

Problem: How to verify propositions in a quantum system.

Solution: Employ Quantum Model Checking.

Challenge: Exponential resource requirements with increasing qubits.

Method: Utilization of specialized data structures and algorithms.

Quantum Compuating Key Concepts

Qubits

Quantum Gates

Superposition

Entanglement

Quantum Compuating example

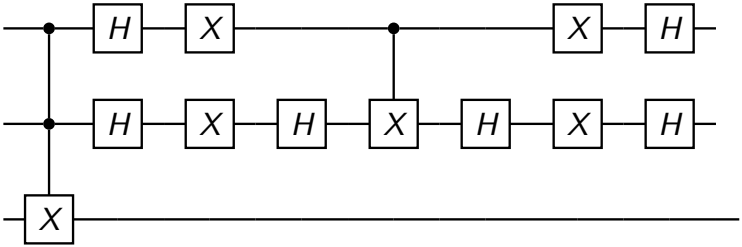


Figure: Quantum circuit of Grover algorithm

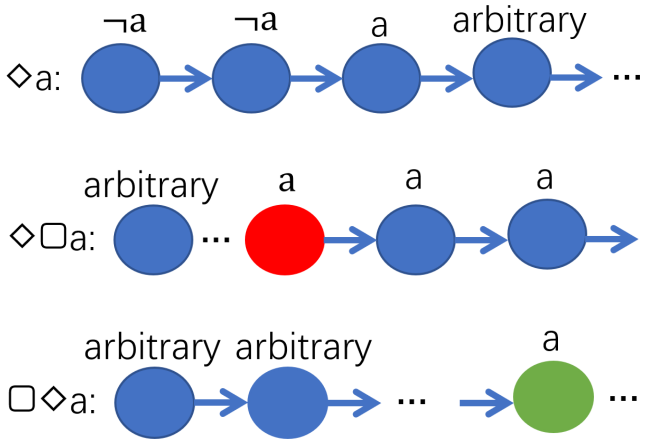
Quantum Transition System

transition system: (S, I, Σ, T)

$$where \begin{cases} x = x_1, \cdots, x_n \\ y = y_1, \cdots, y_n \\ \sigma = \sigma_1, \cdots, \sigma_m \end{cases}$$

Quantum transition system: $(\mathcal{H}, \mathcal{H}_0, Act, \{U_\alpha, \alpha \in Act\})$

Reachability problem



Quantum Logic

Subset relation $\subseteq$ in $S(\mathcal{H})$: Partial order, implies quantum implication.

Orthogonal complement $\mathcal{X}^{\perp}$: Represents negation.

Closed under intersection: $\bigcap_i \mathcal{X}_i \in S(\mathcal{H})$, denotes conjunction.

Union of subspaces: $\bigvee_i \mathcal{X}_i = \text{span}\,(\bigcup_i \mathcal{X}_i)$, interprets disjunction.

Quantum Model Checking example

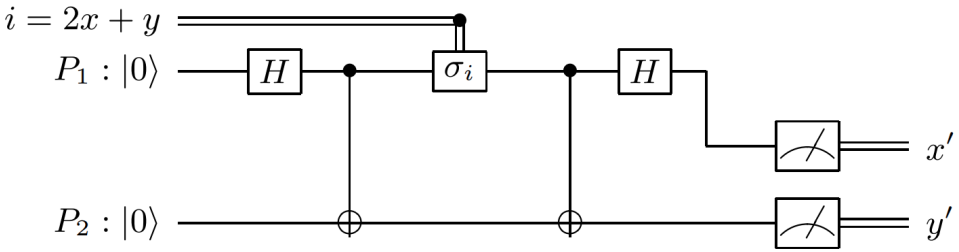


Figure: the purpose of early research

Quantum Model Checking example

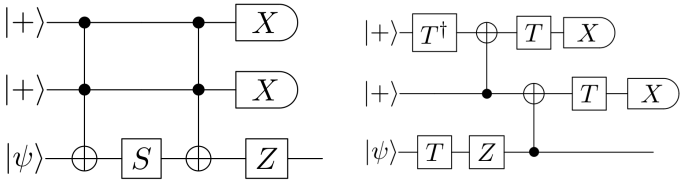
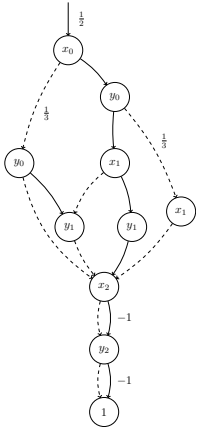


Figure: Circuit Equivalence Checking

Tensor Decision Diagram

$$P = \frac{1}{6}\begin{bmatrix} 1 & -1 & 1 & -1 & 1 & -1 & 0 & 0 \\ -1 & 1 & -1 & 1 & -1 & 1 & 0 & 0 \\ 1 & -1 & 1 & -1 & 1 & -1 & 0 & 0 \\ -1 & 1 & -1 & 1 & -1 & 1 & 0 & 0 \\ 1 & -1 & 1 & -1 & 1 & -1 & 0 & 0 \\ -1 & 1 & -1 & 1 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 3 & -3 \\ 0 & 0 & 0 & 0 & 0 & 0 & -3 & 3 \end{bmatrix}$$



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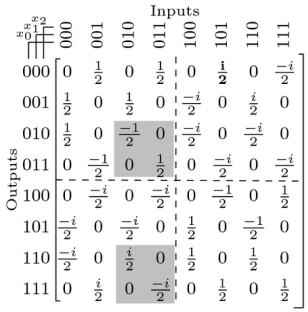
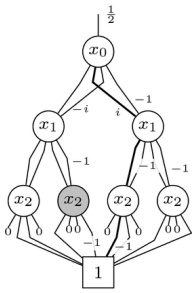
Related work



(a) Matrix



(b) QMDD

Related work

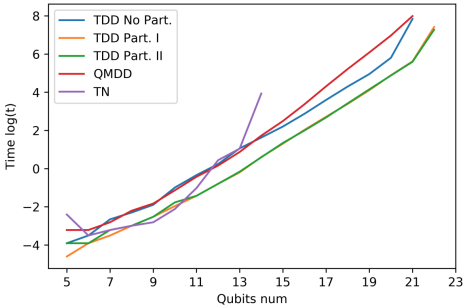


Figure: time consumption for constructing the functionality of qft circuits

Additional

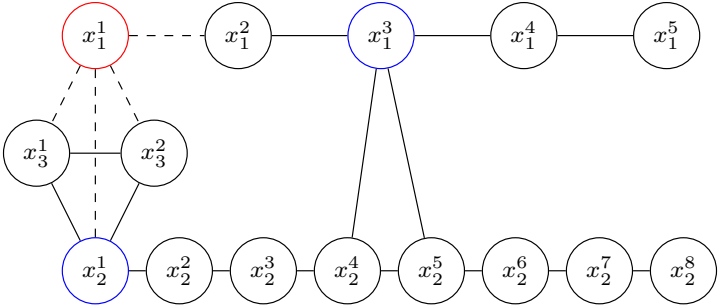


Figure: addition partition

Contraction

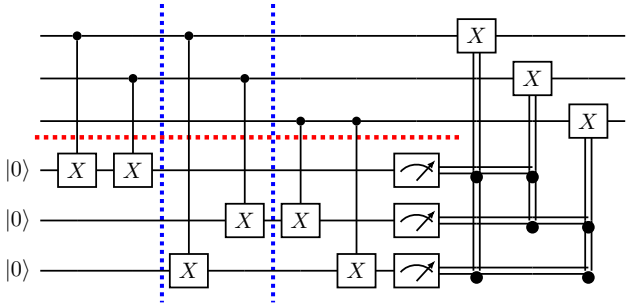


Figure: contraction partition

Results

benchmark	basic	addition	contraction
Grover 20	$\sim$5min	$\sim$4min	$\sim$4sec
Quantum Fourier Transform 20	$\sim$20min	$\sim$11min	$<$1sec
Quantum Random walk 20	$\sim$6min	$\sim$4min	$\sim$15sec
Bernstein-Vazirani 50	$\sim$4min	$\sim$4min	$\sim$16sec
GHZ 500	$\sim$3sec	$\sim$1.5sec	$\sim$1.7sec

Table: Quantum Image computation

Local Invertible Map-DD

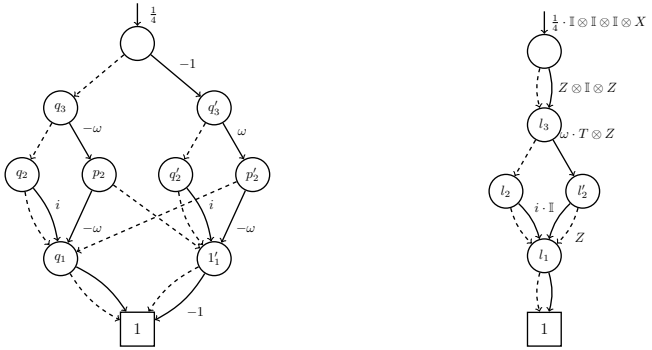


Figure: future plan

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