科研成果认定说明

高丁超

尊敬的各位老师：

本人于 2021 年 9 月进入软件所计算机科学国家重点实验室开始硕士研究生的学习，导师为应圣钢副研究员，主要研究方向是量子计算机。我将申请参加 2024 年夏季硕士学位论文答辩。本文将介绍我在硕士学习阶段所完成的研究工作，以及研究成果中本人的具体贡献。从而方便各位老师了解我的科研工作，并给出认定。

研究成果简介： 在硕士研究期间，本人主要参与了基于 TDD 的量子模型检测工具的开发。TDD 是一种针对量子计算机优化的数据结构，在表示量子线路的张量网络上有显著优势。量子模型检测是一种自动化验证量子系统是否满足特定命题的方法。随着量子系统中量子比特的增加，量子模型检测存在资源爆炸的缺点。使用 TDD 作为量子模型检测的基础，可以显著降低量子模型检测中的资源消耗。

研究成果贡献说明： 在应用 TDD 进行量子模型检测的工具开发过程中，本人主要参与了对 TDD 结构进行拆分，从而进一步优化量子模型检测执行效率的方案设计与 python 代码实现。同时本人负责所有不同优化方案的对比实验设计与 python 代码实现。后续工作中，本人也参与了 C++ 语言版本中，TDD 结构的实现，以及进一步改进 LimTDD 的 C++ 版本实现。

研究成果投稿情况： 基于 TDD 的量子模型检测的科研工作，已将研究成果总结为一篇论文。其中本人作为第二作者。该成果开始是投了 CCF-B 的 ICCAD，结果是拒稿。五分制下，三位审稿人的评分分别是 2，4，4。具体意见可见附录一。后来这篇论文投了 CCF-A 的 DAC，结果是 Work-in-Progress (WIP) poster sessions at the 61th DAC，也就是只展示海报。五分制下四位审稿人的评分都是 3。具体意见可见附录二。

综上所述，本人在硕士研究期间所完成的工作有一定科研价值。诚挚希望各位老师能够对我的研究成果给予 **2 分认定**。

申请人签字: 导师签字:

专家评价意见

专家一意见:

专家二意见:

专家三意见:

附录一 ICCAD 审稿意见

转发: Your ICCAD 2023 Submission (Number 568)

XIN HONG <XIN.HONG@student.uts.edu.au>
周五 2023/11/3 15:20
收件人:by.gdc@outlook.com <By.gdc@outlook.com>

发件人: start@z.softconf.com <start@z.softconf.com> 代表 Program Chair, ICCAD 2023 <iccad2023_n@softconf.com>
发送时间: 2023年7月26日 5:24
收件人: XIN HONG <xin.hong@student.uts.edu.au>
主题: Your ICCAD 2023 Submission (Number 568)

Dear Xin Hong:
I am sorry to inform you that the following submission was not selected by the program committee to appear at ICCAD 2023:
    Image Computation for Quantum Transition Systems
The selection process was very competitive. A total of 748 papers have gone through the complete review process. Because of time and space limitations, we could only choose a small number of the submitted papers to appear on the program.
I have enclosed the reviewer comments for your perusal. The review comments are also available in your Softconf console. Please remember to update your Softconf email address to obtain the latest updates.
If you have any additional questions, please feel free to get in touch.
Best Regards,
Jinjun Xiong, Program Chair, ICCAD 2023
ICCAD 2023

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============================================================================
ICCAD 2023 Reviews for Submission #568
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Title: Image Computation for Quantum Transition Systems
Authors: Xin Hong, Dingchao Gao, Shenggang Ying, Sanjiang Li and Mingsheng Ying


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                            REVIEWER #1
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Reviewer's Scores
---------------------------------------------------------------------------
                Relevance to ICCAD (1-5): 3
        Novelty of technical ideas (1-5): 3
               Theoretically sound (1-5): 3
                Practically useful (1-5): 3
      Thoroughness of the research (1-5): 2
              Clarity and language (1-5): 2
            Overall Recommendation (1-5): 2

Summary
---------------------------------------------------------------------------
This paper presents a basic algorithm and a set of optimization techniques to
calculate the image for quantum transition systems based on the tensor-network
representation of the quantum systems. This idea can be used to conduct model-
checking for quantum circuits.
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Strengths

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1. The topic is timely and interesting.
2. The problem is complex and requires a lot of effort.

Weaknesses

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1. The motivation, challenge and benefit of the proposed system are not clear.
2. The writing needs improvement.
3. Not sure what is the success metric.

Detailed Comments

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1. I am not sure I understand why the proposed system is needed. A lot of assumptions need clarification. For example, why does the quantum circuit need model checking? What is an "image"? An image in this scenario seems to be an intermediate state during the involvement of a quantum system.

2. The proposed system is tightly related to the tensor-network representation of the quantum systems. It is useful to clarify what are operations available from a tensor-network perspective and what are unique features proposed by this work.

3. In addition, the tensor network is known as not suitable for noise simulation. This work seems to aim to model how the errors/noise impact the quantum system and how its tensor network gets transitioned. It would be great to see if this is the goal, but it seems that at least this is not the goal of the current version of the paper.

4. It is not clear how exactly the model checking task is conducted over quantum systems, and why the proposed image calculation framework can help.

5. The evaluation section needs to be restructured: what are the research questions that need to be answered? How do you call yourself successful? etc.

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REVIEWER #2

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Reviewer's Scores

Relevance to ICCAD (1-5): 5
Novelty of technical ideas (1-5): 4
Theoretically sound (1-5): 4
Practically useful (1-5): 3
Thoroughness of the research (1-5): 3
Clarity and language (1-5): 4
Overall Recommendation (1-5): 4

Summary

The authors aim to implement model checking (via image computation) for quantum transition systems.

Strengths

Well written paper.

Good speedup results.

Weaknesses

Lack of complexity analysis

Detailed Comments

1- The introduction lacks emphasis on the contribution of the work. The authors should highlight the significance of their algorithms and provide some initial results to support their claim of improved efficiency in image computation for quantum transition systems.

2- The complexity of the implementation is not discussed. Quantum circuits with a large number of qubits and complex operations can lead to high-dimensional images, making visualization and comprehension challenging as the quantum system size increases.

3- It would be beneficial for the authors to delve into the topic of information loss. Since quantum states are described by complex probability amplitudes, visual representations may not fully capture their intricacies. Image computations often simplify or aggregate information, potentially resulting in the loss of fine-grained details and subtle quantum effects.

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REVIEWER #3

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Reviewer's Scores

Relevance to ICCAD (1-5): 3
Novelty of technical ideas (1-5): 2
Theoretically sound (1-5): 4
Practically useful (1-5): 2
Thoroughness of the research (1-5): 3
Clarity and language (1-5): 3
Overall Recommendation (1-5): 4

Summary

This paper develops efficient image computation algorithms based on tensor networks and tensor decision diagrams, advancing model checking for quantum systems. Experimental results demonstrate the significant improvements in efficiency for image computation in quantum transition systems achieved by proposed contraction partition-based algorithm.

Strengths

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1. This work is theoretically sound.
2. The proposed method is effective in the evaluated benchmarks.

Weaknesses

The article does not explicitly specify the scope of applicability for the proposed methods.

Detailed Comments

The formal verification of the quantum system is important from the long-term perspective. This work introduces TDD-based methods for efficient model verification of quantum systems and achieves satisfactory results on several benchmarks. The presentation of this paper is theoretically sound and logically coherent.

However, I have some concerns regarding the scope of this paper.

1. Does this approach work for "quantum hardware"? In the introduction, the authors claim that "Notwithstanding these achievements, applications of model checking to quantum hardware verification is still an under developed research area." However, in my perspective, this work focuses on verifying quantum circuits, which are graphical representations of quantum programs and do not encompass the concept of 'quantum hardware' that typically refers to physical implementations such as superconducting quantum chips.
2. I would suggest the authors to clearly illustrate what kinds of quantum circuits their approach is effective for. It is known that TDD are compact representations of quantum systems, but I think it is not that useful for arbitrary quantum circuits since a quantum system with randomized states can be hardly represented in this version. Moreover, the evaluation is done on only 5 kinds of quantum circuits and does not cover important NISQ variational algorithms, thus it is difficult to justify whether this approach is practically useful in NISQ era.

There're some minor issues with this paper.
1. The description of Fig. 1 and the labels of the figure do not match. The TDD shown in the figure starts from x_0, y_0, while the text description starts from x_1, y_1.
2. According to Fig. 1 (right) and the definition of TDD. The value $\phi_{x_1x_2x_3y_1y_2y_3}(110111)$ should be "-1/2 \times 1 \times 1 \times 1 \times 1 \times 1 \times -1", i.e., five 1s rather than four.
3. The "index terms" are missing below the abstract.

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ICCAD 2023 - https://softconf.com/n/iccad2023

附录二 DAC 审稿意见

转发: 61 DAC: Notification of your submitted work (Submission ID 1199)

XIN HONG <XIN.HONG@student.uts.edu.au>
周三 2024/2/28 9:56
收件人:Mingsheng Ying <mingshengying@gmail.com>;Sanjiang Li <Sanjiang.Li@uts.edu.au>;yingsg <yingsg@ios.ac.cn>;by.gdc@outlook.com <By.gdc@outlook.com>

发件人: 61 DAC Program Management <research_dac24@softconf.com>
发送时间: 2024年2月27日 10:21
收件人: XIN HONG <xin.hong@student.uts.edu.au>
主题: 61 DAC: Notification of your submitted work (Submission ID 1199)

Congratulations! On behalf of the DAC Technical Program Committee, we are pleased to inform you that your manuscript "Image Computation for Quantum Transition Systems" was selected to present a poster at one of the **Work-in-Progress (WIP) poster sessions** at the 61th DAC, June 23-27 in San Francisco, CA.
By **Wednesday, March 13**, you must log into the submission portal and confirm your agreement with the terms of acceptance. This includes: at least one (1) author of your poster will register for the event and attend in-person to present the poster; a unique full conference registration will be associated with each accepted poster by the registration deadline (April 10).
To confirm or decline your acceptance:

- Log into Softconf
- Choose "Your Current Submissions" and then select your paper
- You'll see an option to revise your WIP confirmation. Select this option, then accept or decline to present.
- If you do not complete your confirmation by March 13 the DAC office will take this as a sign that you do not wish to participate in the 2024 DAC Work-in-Progress session and your submission will be deleted from the DAC submission system.

**PLEASE NOTE: A WIP poster presentation at DAC is not considered a publication and no paper will be published. WIP authors can submit their work to other conferences and journals without violating any pre-publication issues or common code of ethics.
Registration Requirement
Registration for 61 DAC will open on March 20. You will receive an email prior to that date with instructions on how to register as an author. If you need assistance with a Visa letter prior to that date, please submit a visa request form at https://www.compusystems.com/servlet/ar?evt_uid=2171&site=INQ.
At least one author of your paper must register by **April 10** in order to have your final paper accepted and to be included in the conference. Please note that each paper must have a unique associated registration. If you are the author on more than one paper, a co-author must register for any additional papers, even if you will present them.
Regards,
David Pan, 61th DAC Technical Program Committee Chair
Chia-Lin Yang, 61th DAC Technical Program Committee Co-Chair
https://softconf.com/dac24/research/
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============================================================================
DAC 2024 Reviews for Submission #1199
============================================================================

Title: Image Computation for Quantum Transition Systems
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Authors: Xin Hong, Dingchao Gao, Shenggang Ying, Sanjiang Li and Mingsheng Ying

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REVIEWER #1
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Reviewer's Scores

Clarity / Writing Style (1-5): 3
Originality / Innovativeness (1-5): 4
Impact of Ideas and/or Results (1-5): 3
OVERALL RECOMMENDATION (1-5): 3

Summarize shortly the contributions of the paper in your own words.

The authors introduce a method for model checking quantum systems based on efficient image computation algorithms. They demonstrate the scalability of their technique on a set of well-known benchmarks.

Strengths

+ ...The paper is in an area of interest to the community.
+ ...The authors cleverly leverage techniques known for classical computing and develop an analogous method for quantum computing.

Weaknesses

- ...This paper was a heavy read, but perhaps cannot be helped due to the concepts being introduced.

Main Discussion of Paper

The authors have developed a method for model checking quantum systems based on efficient image computation algorithms. Their technique uses tensor networks to represent the quantum circuits and tensor decision diagrams to create the efficient image computation algorithm. They have developed a scalable technique leveraging concepts used in classical computing. They go on to demonstrate the scalability of their technique on a set of well-known benchmarks and show that their contraction partition algorithm greatly improves the image computation for quantum systems.

I found this paper difficult to read, but this was due I believe to my not being familiar with the classical technique that they leveraged in their work. The work seems well-conceived and the carried out.

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REVIEWER #2
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Reviewer's Scores

Clarity / Writing Style (1-5): 5
Originality / Innovativeness (1-5): 3
Impact of Ideas and/or Results (1-5): 3
OVERALL RECOMMENDATION (1-5): 3

Summarize shortly the contributions of the paper in your own words.

The paper presents an efficient quantum extension of a classical model checking technique called image computation. The proposed approach uses Tensor Decision Diagram networks to represent the quantum circuit under evaluation in a compact form. Lastly, a pair of partition-based image computation methods are proposed which dramatically improve the baseline efficiency of performing quantum image computation.

Strengths

+The paper is well written.
+Results show that the proposed method scales well for many quantum circuits, notably QFT.

Weaknesses

-No comparison is provided between the proposed image computation method(s) and other quantum model checking methods.
-Relative lack of discussion of the effects of partition parameters.
-Discussion of results is limited to one short paragraph regarding Table 1 and two sentences regarding Table 2

Main Discussion of Paper

The paper is well written and provides detailed background information and explanation of the basic components of the proposed method. Additionally, the results demonstrate that, while the basic and addition partition quantum image computation methods perform poorly, the contraction partition method provides significant improvements in runtime and memory usage. However, no discussion or results are provided which compare the utility or performance of the proposed quantum image computation method with other quantum model checking methods.

Relatively little discussion is provided for the parameters of either partition method, such as how (or if) good values for the parameters are expected to be different for different circuits. Also notable is the lack of discussion regarding the fact that exceptionally small values of the contraction partition parameters (which amount to simply considering all qubits and/or multi-qubit gates separately) perform very well.

Lastly, although the paper is well written, the proposed method seems to be a relatively natural extension of existing methods in classical model checking and quantum computing, and thus not particularly innovative. Additionally, the paper has not convincingly demonstrated the importance of this work as compared with other quantum model checking methods, and thus may not be particularly impactful.

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                            REVIEWER #3
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Reviewer's Scores
----------------------------------------------------------------------------
           Clarity / Writing Style (1-5): 4
      Originality / Innovativeness (1-5): 3
    Impact of Ideas and/or Results (1-5): 2
            OVERALL RECOMMENDATION (1-5): 3

Summarize shortly the contributions of the paper in your own words.
----------------------------------------------------------------------------
This paper proposes two tensor network partition-based approaches for the image
computation of a quantum transition system. The image computation is used for
model checking of a quantum circuit.
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Strengths
----------------------------------------------------------------------------
1. Clear explanation of concepts and provide useful examples.
2. Strong numerical evidence on reducing computation time and memory compared to
baseline.
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Weaknesses
----------------------------------------------------------------------------
1. Lack of evaluation on dynamic and noisy circuits.
2. Not clear how the paper checks correctness of image computation.
3. Lack concrete introduction of the usage of image computation in model checking
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Main Discussion of Paper
----------------------------------------------------------------------------
The paper proposed two tensor network partition-based algorithms for image
computation of quantum transition systems. The proposed methods (especially the
contraction partition) show improvements over the baseline method. In terms of
scaling, it is very promising as it can handle problem sizes up to 500 qubits.
However, one primary concern of the work needs to be clarified.

How this work ensures the correctness of image computation needs to be clarified.
It is great to see reductions both in computation time and memory. The authors
should have at least a fidelity/error measure to quantify the quality of image
computation. After all, we want to check model equivalence between a large-size
quantum circuit and classical computation of various input states through subspace
projectors.

On the other hand, the authors consider dynamic and noisy quantum circuits to be
transition systems. The methods proposed should also be applied to those two types
of circuits. Such evaluations are lacking in the current study. Are there any
fundamental difficulties? Noisy quantum circuits require density matrix simulation
and are much more expansive than state-vector simulation.

In the end, it is worthy to introduce more how does the image computation is used
in the model checking of a quantum circuit.
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                            REVIEWER #4
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Reviewer's Scores
---------------------------------------------------------------------------
           Clarity / Writing Style (1-5): 4
      Originality / Innovativeness (1-5): 3
    Impact of Ideas and/or Results (1-5): 4
            OVERALL RECOMMENDATION (1-5): 3

Summarize shortly the contributions of the paper in your own words.
---------------------------------------------------------------------------
The paper provides efficient image computation algorithms for quantum transition
system for quantum system model checking. The approach taken by the paper
represent quantum circuits as tensor networks and design algorithms by leveraging
the properties of tensor networks and tensor decision diagrams.
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Strengths
---------------------------------------------------------------------------
+ A range of quantum circuits has been covered for evaluation.
+ For each circuit, qubit number is also tuned for evaluation.
+ Significant improvement shown in run time and number of nodes.
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Weaknesses
---------------------------------------------------------------------------
- The impact of parameters for contraction partition is discussed but the reason
is not clear.
- The correctness of the proposed image computation algorithm is not validated.
- There is no comparison with other quantum model checking methods.
---------------------------------------------------------------------------


Main Discussion of Paper
---------------------------------------------------------------------------
This paper describes an approach for using image computation algorithms for
quantum system model checking. A wide range of quantum algorithms has been
considered, which is good, and for each circuit, the qubit number was tuned for
evaluation. The authors show significant runtime improvement using their
technique. However, the correctness of this method has not been validated. And,
the impact of the parameters for the contraction partition is not clear. Lastly,
there isn't a comparison with other model checking techniques.
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