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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Andrey Kardashin

PhD Program: Computational and Data Science and Engineering

Title of Thesis: On applications of variational quantum circuits

Supervisor: Professor Jacob Biamonte

Name of the Reviewer: Dr. Zoltán Zimborás

I confirm the absence of any conflict of interest.	**Date: 11-04-2022**

Reviewer's Report

Classical computers face significant challenges when it comes to tackling complex quantum systems and solving other large dimensional problems. While quantum computers hold promise for solving these issues, the availability of fault-tolerant quantum computers remain uncertain in the near future. Current quantum devices suffer from constraints, such as limited qubits and noise-induced circuit depth limitations. As a solution, variational quantum algorithms (VQAs) have emerged as a leading strategy that employs a classical optimizer to train a parameterized quantum circuit, helping to address these constraints. Researchers have proposed VQAs for practically all quantum computing applications, and they appear to offer the most promising approach for achieving quantum advantage. Andrey Kardashin's thesis on variational quantum algorithms is thus a very timely work. It studies the utilization of VQAs for quantum many-body physics, for quantum machine learning tasks, and also explores the deep connection between VQAs and tensor networks.

The thesis is well-organized, coherent and has a clear overall structure. The 132-page-long thesis is divided up into four chapters (and three appendices) in a very natural manner: Chapter 1 introduces the readers to the notations, the mathematical tools and the basics of quantum computing that will be used throughout the rest of the thesis. Chapter 2 focuses on variational quantum computing, specifically the Variational Quantum Eigensolver (VQE) algorithm. The chapter covers experimental, numerical as well as analytical work. The author reviews the experimental realization of VQE for finding the ground state energy of the two-qubit Schwinger Hamiltonian, and presents numerical and analytical work about the VQE approach to a spin-chain Heisenberg Hamiltonian with Dzyaloshinskii-Moriya interactions. Chapter

3 provides a formulation of various variational quantum algorithms in the tensor networks notation. By utilizing this notation, the chapter reveals interesting properties of these algorithms. Notably, it demonstrates that these algorithms can be reduced to the VQE algorithm executed for a particular Hamiltonian and variational state. In addition, this chapter also shows that variational quantum circuits can be used to build a quantum classifier that can distinguish between quantum channels, even with a small training set and random, unknown input states. Chapter 4 discusses the use of variational quantum circuits for solving machine learning tasks, specifically for quantum channel discrimination. This approach is shown to distinguish between two depolarizing and two entanglement-breaking channels with successful discrimination probabilities achieving the upper bound given by the diamond-norm distance. In addition, the chapter also shows that variational quantum circuits can be used to build a quantum classifier, that distinguishes between quantum channels, even with a small training set and random, unknown input states.

The thesis and its results clearly reveal the ability of the author to interconnect and extend knowledge from multiple disciplines: quantum computing, quantum many-body physics, quantum machine learning and tensor networks. The numerical methods are convincing and the rigor of the analytical methods are praisable. The international scientific significance of the results are high. The candidate has four first-author papers and is co-author in two other papers. I think this is quite good for a PhD student. All the papers have high quality.

In summary, the thesis of Andrey Kardashin presents original research results in the area of variational quantum algorithms that is of large importance. It fulfills all demands required by a doctoral thesis. I can recommend without hesitation that the candidate should defend the thesis by means of a formal thesis defense.

Provisional Recommendation

☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*

☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*

☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*