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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Akshay Vishwanathan

PhD Program: Computational and Data Science and Engineering

Title of Thesis: On quantum approximate optimization

Supervisor: Professor Jacob Biamonte

Name of the Reviewer: Evgeniy Kiktenko

I confirm the absence of any conflict of interest	**Date: 17.04.2023**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

The thesis consists of three introductory chapters, three chapters dedicated to the results that were obtained, and a conclusion. Overall, I find the text to be well written and concise.

The main topic of study is on quantum approximate optimization algorithm (QAOA) which is a variational algorithm tailored towards realizing classical optimization on near term quantum devices. Variational algorithms such as QAOA have attracted widespread attention recently and are often considered as the de-facto model for modern day noisy quantum processors. Furthermore, approximate solving of NP-Hard problems is an active area of research in quantum computation and it is believed that variational approaches such as QAOA could potentially offer advantages over classical computation. However, the prospects of employing QAOA still remain largely open. In the thesis an attempt is made to investigate fundamental effects that aid or limit the QAOA's use case. Therefore, the thesis topic is indeed relevant to its contents.

The results described in the thesis are obtained mostly from numerical experiments and the details on the methodology is adequately given. Wherever applicable, mathematical proofs are also employed.

The thesis makes the following main contributions:

1) A limiting feature for QAOA called reachability deficits are identified and studied.
This effect eludes towards low depth benefits for QAOA circuits to only admit low-problem density instances. Deeper circuits, though practically challenging, become a necessity in the framework of QAOA.

2) An aiding effect for optimal QAOA circuit parameters, called parameter concentration is demonstrated for the case of variational state preparation.
This effect is of practical importance in training QAOA circuits on instances with large problem

sizes. If valid in a general setting, the training cost of optimizing QAOA circuits can significantly be reduced.

3) An empirical methodology is proposed to recover circuit depth scaling for QAOA applied to the problem of maximum satisfiability.
Circuit depth scaling is of significant importance as they pave a way towards identifying the kind of resources a quantum device would require to attain advantage, if any, over best-known classical algorithms.

All the results are novel and as indicated above, have theoretical and practical importance. Moreover, the results are reported in 4 publications in refereed journals (Physical Review Letters, Physical Review A, and Quantum) indexed in Scopus and Web of Science.

Questions to be addressed:
1) In training QAOA circuits, a strategy motivated by layer-wise training is employed. The justification provided is to escape local minima in the cost function landscape. Can the author provide additional information (either in terms of numerical evidences or analysis) that can support this claim?

2) How the investigated phenomenon of reachability deficits relates to the problem of barren plateaus and local minima usually considered as major obstacles for variational algorithms?

(The questions do not detract from the high value of the work and are advisory in nature.)

☒ *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*