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Reviewer's report on PhD thesis

Reviewer: doc. RNDr. Jan Bouda, Ph.D.

PhD candidate: Mgr. Ing. Lukasz Pawela

Summary

The main subject of this PhD thesis is to study concepts of quantum information processing in the context of open quantum systems. This thesis is composed as a collection of five papers with a short common introduction. All these papers were published in an impacted journal. These papers are a topic-selected subset of the whole publication record of the candidate.

The areas addressed by the thesis are quantum games (ref. 1), quantum control (ref. 2-4), and quantum channels (ref. 5). Possible questions the candidate should answer during the defense are typeset in *italics*.

Quantum games

Candidate studied the penny flip game in the context of open quantum systems. They used existing framework describing noisy operations of this game in terms of Hamiltonians and time evolution, to include effects of environment. Candidate conducted the study for three types of noise – amplitude damping, amplitude raising, and phase damping.

The central interest seems to be on the Nash equilibria of the game. Candidate notes on p. 673 that, due to the noise, the strategies in Table 2 are no longer Nash equilibrium. This does not seem to be straightforward – this is obviously true for gamma=1, but not for gamma=0. I would be curious whether candidate can comment on this further – do the Nash equilibria exist for various values of gamma. Do they change continuously with gamma?

It seems candidate did further analysis toward finding equilibria for particular noise intensities. However, it seems they did only partial optimizations towards this goal (e.g. optimization of payoff for one player while the other player's strategies are restricted).

Also, I'm a bit puzzled by p. 675 – "in each round, one player performs a series of unitary operations chosen randomly from a uniform distribution". I assume uniform distribution here is the Haar distribution, but the selecting a number of unitaries and applying them sequentially makes no sense, since they will only establish together one Haar-random unitary.

Quantum control

In refs. 2-4 candidate uses various optimization methods to optimize control pulses in various settings. In ref. 2 candidate wants to implement a unitary operation, and preserve its coherence by adding ancillary systems and using control pulses. He presented three optimization methods to calculate appropriate control parameters – approximate mapping method, approximate gradient method, and genetic programming, and tested them on examples of NOT and SWAP gate. In ref. 3 candidate addresses possible hardware restrictions on implementing quantum control, namely restrictions on frequency spectrum. In ref. 4 an undesirable property of control pulses is studied – entangling the target systems to environment. This introduces additional optimization parameters that are addressed. In the optimization procedure.

I have to stress that I'm not an expert on quantum control. Therefore I cannot comment on *how realistic and general is the model of control pulses and related issues (e.g. entangling effect of control) used here, neither how innovative are these result in contrast to other (analytical) results. It would be good if the candidate can comment on that. Another question is whether the model of spin chain used is sufficiently interesting for practical purposes.*

Quantum channels

Candidate introduces a new quantity – superfidelity of quantum channels. Candidate shows some properties of the channel superfidelity, and a circuit allowing experimental estimation of superfidelity, that is simpler in contrast to fidelity estimation. Candidate further tests practical properties of the superfidelity by testing how it behaves on particular channels, namely how it measures difference between a unitary and an erasure channel, and sensitivity to changes of the Hamiltonian.

The usual motivation of superfidelity is to upper-bound fidelity by a quantity easier to evaluate. *A bit puzzling here is the definition of channel fidelity (Def. 13) that only measures fidelity between input and output of a particular channel. On contrary, the superfidelity introduced in Def. 14 compares fidelity of outputs of two channels, and hence, compares to the fidelity as of Def. 13 if you fix one of the channels to be identity. Does this generalization bring complications in evaluation? What are the situations when you want to use it? (in addition to Corollary 1-3).*

I am not completely sure about the approach candidate took to test the properties of the superfidelity. Why are these particular examples interesting? Also, the question is whether you want to test how well superfidelity distinguishes two quantum channels, or rather how well it measures some quantity with well established operational meaning – such as the trace norm distance.

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Conclusion

Candidate presented a number of original solutions to particular research problems, namely Nash equilibria of noisy coin flip game, the problem of (practical/experimental) quantum channel discrimination/estimation, and optimal quantum control in various settings. Along the way he also demonstrated a general theoretical knowledge of the field, spanning relevant areas of computer science, mathematics and physics.

By his personal contribution to the results included in the thesis, candidate demonstrated that he can independently participate on all fundamental aspects of theoretical research, namely finding and identifying a research problem, analyzing the problem, solving it, and writing the actual paper.

Candidate has proven his ability for independent scientific work. I recommend to accept this thesis.

In Brno on April 24th 2017

Jan Bouda J. Bouda

doc. RNDr. Jan Bouda, PhD.
Faculty of Informatics, Masaryk University
Botanická 68a, 602 00, Brno
Czech Republic