Thesis Proposal **Luis Barbosa, Vítor Fernandes, Renato Neves**
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Equivalence for Quantum Processes: from theory to practice

Motivation and Goals

From coherently handling a few qubits to dozens of them, viable quantum computers seem closer to us than ever. One of many milestones that attest to this rapid progression is Google's quantum computer *Sycamore*, which can solve a particular task in a few minutes whilst current supercomputers require at least a few days. Despite all progress made, however, we are still far away from noise-free, ideal quantum computers. In fact, we are just now approaching an era of *noisy intermediate-scale quantum* (NISQ) computers [Pre18]: i.e. noise-susceptible devices, with only a few hundred qubits, but still of potential use in specialised, small tasks.

A computer architecture that stands out in this NISQ era is QRAM [Kni96]: in a nutshell, a master-slave architecture in which a *classical* computer (the master) handles a complex task by sensibly marking costly computational subtasks and requesting a quantum computer (the slave) to solve them. Such an architecture is necessary because NISQ computers become increasingly unreliable as their computational tasks grow in size.

Such an interaction between classical and quantum computers highlights the importance of harbouring both concurrency and communication in models of quantum programming languages. In particular, it calls for principled extensions of *process algebra* [Fok13, BPS01] to the quantum domain. This was already tackled, for example, in [FDY12, GN05], two works that introduce quantum process algebras inspired on CCS and π-calculus. Unfortunately, tool support for quantum process algebras is still very limited, which hinders their application to real-world scenarios. A most striking example is the general lack of *automated tools* for checking whether two quantum processes are equivalent [ALGN18, Den18].

The goal of this project is to implement an automated tool that checks whether two quantum processes are equivalent. To achieve this, we will base on a previously developed notion of *symbolic bisimulation for quantum processes*, which is particularly amenable to implementations [FDY14] (in fact, a corresponding algorithm was already proposed in [FDY14]).

Research Plan

This work requires some time to study process algebra [Fok13, BPS01]. It also requires some time to study its extensions to the quantum domain [FDY12, GN05], and different notions of (symbolic) bisimulation for both probabilistic and quantum processes [Den18]. The first three months of the project will thus be devoted to studying these topics. The next three months will consist in implementing the algorithm proposed in [FDY14]. In the remaining time, we will select a collection of case-studies concerning quantum computing (e.g. quantum teleportation and BB84) and use it to benchmark and illustrate the proposed implementation.

References

[ALGN18] Ebrahim Ardeshir-Larijani, Simon J Gay, and Rajagopal Nagarajan. Automated equivalence checking of concurrent quantum systems. *ACM Transactions on Computational Logic (TOCL)*, 19(4):1–32, 2018.

[BPS01] Jan A Bergstra, Alban Ponse, and Scott A Smolka. *Handbook of process algebra.* Elsevier, 2001.

[Den18] Yuxin Deng. Bisimulations for probabilistic and quantum processes. In *29th International Conference on Concurrency Theory (CONCUR 2018)*. Schloss Dagstuhl-Leibniz-Zentrum fuer Informatik, 2018.

[FDY12] Yuan Feng, Runyao Duan, and Mingsheng Ying. Bisimulation for quantum processes. *ACM Transactions on Programming Languages and Systems (TOPLAS)*, 34(4):17, 2012.

[FDY14] Yuan Feng, Yuxin Deng, and Mingsheng Ying. Symbolic bisimulation for quantum processes. *ACM Transactions on Computational Logic (TOCL)*, 15(2):1–32, 2014.

[Fok13] Wan Fokkink. *Introduction to process algebra.* springer science & Business Media, 2013.

[GN05] Simon J Gay and Rajagopal Nagarajan. Communicating quantum processes. In *Proceedings of the 32nd ACM SIGPLAN-SIGACT Symposium on Principles of Programming languages*, pages 145–157, 2005.

[Kni96] Emmanuel Knill. Conventions for quantum pseudocode. Technical report, Los Alamos National Lab., NM (United States), 1996.

[Pre18] John Preskill. Quantum computing in the nisq era and beyond. *Quantum*, 2:79, 2018.