Master-thesis: Gradient measurements for variational hybrid quantum-classical algorithms

1 Background

Quantum computers can outperform classical computers on certain classes of problems and solve problems that are intractable even on any future (classical) supercomputer. The development of chips for quantum computers has been following Moore's law in the last years and the technology is edging ever closer to commercialization. Every new generation of quantum chips represents an improvement not only in the number of quantum bits, but also with respect to the error rates and the connectivity of the quantum bits. Most of these small scale quantum computers are accessible through cloud interfaces today. The first generation of practically-relevant quantum computers will be noisy intermediate-scale quantum (NISQ) computers. This means that calculations will have errors and the length of a computation will be relatively short. A family of methods that lend themselves well to NISQ devices are hybrid methods based on the variational principle. A general overview is provided in, e.g., [3].

2 Problems to be studied

Classical optimization procedures to find the optimal variational parameters can be devided into gradient-free and gradient based. Gradient information can be used to improve convergence and reliability, particularly for NISQ devices. There is a range of different techniques, see e.g., [4, 5, 2, 1] and references therein. There is also an online tutorial available here[1].

3 Goals of the project

There are three primary goals of the project:

1. Developing a sound theoretical understanding of variational quantum-classical algorithms, including basic principles and current state of the art.
2. Implementing and testing optimization procedures primarily based on gradient information on simulators and actual quantum computers. For execution on real devices, it is suggested to use e.g., IBM's gate based quantum computers available free online.
3. Time allowing, improvements on existing approaches can be developed.

References

[1] Leonardo Banchi and Gavin E Crooks. Measuring analytic gradients of general quantum evolution with the stochastic parameter shift rule. *Quantum*, 5:386, 2021.

[2] Aram W. Harrow and John C. Napp. Low-depth gradient measurements can improve convergence in variational hybrid quantum-classical algorithms. *Phys. Rev. Lett.*, 126:140502, Apr 2021.

[3] Nikolaj Moll, Panagiotis Barkoutsos, Lev S Bishop, Jerry M Chow, Andrew Cross, Daniel J Egger, Stefan Filipp, Andreas Fuhrer, Jay M Gambetta, Marc Ganzhorn, Abhinav Kandala, Antonio Mezzacapo, Peter Müller, Walter Riess, Gian Salis, John Smolin, Ivano Tavernelli, and Kristan Temme. Quantum optimization using variational algorithms on near-term quantum devices. *Quantum Science and Technology*, 3(3):030503, June 2018.

[4] Maria Schuld, Ville Bergholm, Christian Gogolin, Josh Izaac, and Nathan Killoran. Evaluating analytic gradients on quantum hardware. *Physical Review A*, 99(3):032331, 2019.

[5] James Stokes, Josh Izaac, Nathan Killoran, and Giuseppe Carleo. Quantum natural gradient. *Quantum*, 4:269, 2020.

[1] Online tutorial `https://pennylane.ai/qml/demos/tutorial_quantum_natural_gradient.html`