Dario Melegari

First Year PhD Report

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Tutor

Prof. Paolo Solinas

Research Activity

My reserach activity focuses on two main fields; the first one is Quantum Non-demolition measurements, and the other one is Quantum Machine Learning.

Quantum non-demolition measurements research: My research activity in this area focused on the study and application of Quantum Non-Demolition Measurements (QNDM) as an alternative and powerful tool to investigate quantum properties of physical systems and, eventually, to improve the efficiency of quantum algorithms.

In the first line of work, we investigated the use of QNDM to test macrorealism violation. Traditionally, this is addressed through the Leggett-Garg inequalities (LGIs), which provide only sufficient conditions to detect quantum behaviour and are very sensitive to noise. We performed a systematic comparison between the two approaches by means of IBM quantum simulators. Our results demonstrated that the QNDM protocol not only allows for a necessary and sufficient condition to establish macrorealism violation (as previously demonstrated by P. Solinas), but also exhibits robustness against device noise. Furthermore, we showed that, in our model, the QNDM protocol requires equal or fewer experimental resources compared to the standard LGIs, making it a promising and practical method for future experimental implementations.

In a second project, I explored the application of QNDM in the context of Variational Quantum Algorithms (VQAs). A well-known bottleneck in VQAs is the evaluation of gradients and higher-order derivatives of quantum observables, a task that is typically resource-intensive. We proposed and analyzed the use of QNDM as an alternative strategy to estimate derivatives, showing that it significantly reduces the computational cost compared to standard gradient evaluation methods. To benchmark the method in realistic scenarios, we applied both traditional and QNDM-based derivative estimation to quantum chemistry problems, specifically the ground state energy optimization of H_2 and LiH molecules. Our simulations showed that the two approaches achieve comparable convergence, while the QNDM method requires fewer resources. These results highlight the potential of QNDM to enhance the scalability and efficiency of VQAs, making it a valuable candidate for implementations on near-term quantum devices.

Overall, my research demonstrates the versatility of the QNDM protocol, both as a fundamental tool for testing quantum foundations and as a practical technique to enhance quantum algorithms. Future directions include the experimental realization of these protocols and their extension to more complex quantum architectures.

Quantum Machine Learning research: In collaboration with Alessandro Verri (DIBRIS-Unige) and Samuele Pignone (DIBRIS-Unige).
Quantum Machine Learning (QML) is one of the newest fields in quantum information which aims to leverage power of quantum mechanics to perform machine learning algorithms, hopefully, in a better way compared to the classical ones. This hope is particularly indicated in Kernel methods, which are known to perform better than neural networks when dealing with small datasets. On the other hand, kernel methods are particularly unsuited for too complicated datasets, for example the so-called *random datasets*, performances of classical

kernel methods are in general poor. By leveraging quanutm Computing capabilities, we are studying how we can improve these performances on real-case scenarios.

Courses

I attended these courses:

QCD and collider physics, S. Marzani, 3 CFU, programmed around the end of September

Advanced Computational Physics, R. Ferrando, 3 CFU, programmed around the end of September

High Performance Computing, D. D'agostino, 3 CFU, programmed around the end of October

I passed these courses:

Energetics in the quantum regime, D. Ferraro, 3 CFU

Atomistic simulations with machine learning based interatomic potentials, U. Raucci and F. Mambretti, 1.5 CFU

LMS Research School - Quantum Machine Learning and Hamiltonian Simulation - Sabhal Mor Ostaig, Skye, 3 CFU

Publications

Resource Reduction for Variational Quantum Algorithms by Non-Demolition Measurements, D. Melegari, R. Abdul Razaq, G. Minuto, P. Solinas
Preprint, arXiv:2503.24090 [quant-ph], 2025, https://arxiv.org/abs/2503.24090

Quantum Simulations of Macrorealism Violation via the Quantum Nondemolition Measurement Protocol, D. Melegari, M. Cardi, P. Solinas,
Physical Review A, vol. 111, no. 5, 052435 (2025), https://doi.org/10.1103/PhysRevA.111.052435

A Novel Approach to Reduce Derivative Costs in Variational Quantum Algorithms, G. Minuto, D. Melegari, S. Caletti, P. Solinas,
Journal of Physics A: Mathematical and Theoretical, vol. 58, no. 18, 185301 (2025), https://doi.org/10.1088/1751-8121/adcf62

Conferences

I attended these conferences:

CESQ Quantum Hackaton, Strasbourg, France, 6th-7th March 2025, attended

International Conference on Quantum Energy, Padua, Italy, 3-6 June 2025, attended

LMS Research School - Quantum Machine Learning and Hamiltonian Simulation, Sabhal Mor Ostaig (Gaelic College), Skye, 8-13 June 2025, attended

Teaching Activities

Tutor of the course "Fisica e Laboratorio di Metodi di Osservazione e Misura" for the Biotechnologies course.