Centre for
Theoretical Atomic, Molecular and Optical Physics
CTAMOP
Queen's University Belfast

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Quantum-data analysis for quantum technologies

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State of the art and motivations

The mathematical models of physical systems offered by theoretical physics is mainly based on observations and measurements. However, it is typically difficult to provide models — and, in general, understanding — of interesting systems, since they are often so complex that measured quantities appear noisy, unclear, and even redundant. In fact, this is a rather a fundamental obstacle in science in general, with examples ranging from disciplines as diverse as neuroscience and meteorology. The number of variables to measure can be unwieldy, at times even deceptive, and the data emerging from the observations can appear meaningless.

In the past decades, various machine learning tools have been developed by data analysts to extract relevant information from confusing data sets — including principal component analysis (PCA), artificial neural networks, and variational autoencoders. Some of these methods provide a roadmap for how to reduce a complex data set to a lower dimension to reveal the sometimes hidden, simplified structures that often underlie it. For example, PCA can construct optimal low-rank approximations from the spectral decomposition of a data matrix. Other methods can be trained on given data, labelled using certain properties of interest, to then classify unseen new data; and others can even discover without supervision new properties of a system.

Quantum physical systems are particularly complex and, recently, various machine learning techniques developed in the context of classical data analysis have been deployed by researchers in quantum technologies to help our understanding of "quantum data" [1, 2] — namely, classical data emerging from measurements on quantum systems (see Fig. 1).

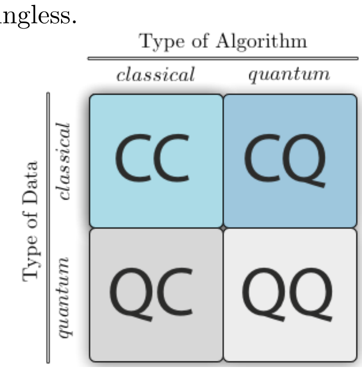

Fig. 1: Four different approaches to combine the disciplines of quantum computing and machine learning. The first letter refers to whether the system under study is classical or quantum, while the second letter defines whether a classical or quantum information processing device is used. Figure and caption adapted from [1].

Objectives & Methodology

The main aim of this project is to consider machine learning algorithms developed to study classical data and apply them to learn information about quantum systems. For example, quantum states are represented by positive semidefinite matrices with exponentially large dimension as a function of the numbers of systems. One can use the PCA method above to construct faithful low-rank approximation of the latter, or extract useful information about quantum features such as entanglement or non-classicality. Also, in the context of quantum computation [3], machine-learning inspired approaches can improve the design of quantum gates [4].

In addition, inherently quantum algorithms for learning either from classical or quantum systems have been recently proposed [2]. A second aim of this project will be to develop proposals for the implementation of these genuinely quantum machine learning algorithms. For example, a protocol called quantum-PCA has been introduced that harnesses the dynamics of some quantum systems. The advantage is that one can perform quantum-PCA of an unknown low-rank density matrix, revealing in quantum form useful information in time much faster than any existing algorithm [5].

Collaborations

The project will involve interactions with long-term international collaborators of the supervisors, including experimentalists as Prof Sciarrino (Rome). Those are recognised experts in the field of quantum information science, and collaborations with them will be of clear benefit.

Required skills

The interested student will have a passionate and inquisitive approach toward mathematics and physics. A good knowledge of Quantum Theory and Mathematical Methods of Physics is required. Advanced computing skills are not required, although the student will become familiar with tools such as Mathematica, Matlab, Python.

Further information

The student will be a member of the Quantum Technology group at Queen's University Belfast and will participate to its activities (group meetings, seminars, meetings with guest scientists) and it is expected the participation at international conferences and schools.

Further information can be requested by contacting Dr Ferraro a.ferraro@qub.ac.uk.

References

[1] https://en.wikipedia.org/wiki/Quantum_machine_learning

[2] M. Schuld, I. Sinayskiy, F. Petruccione, Contemporary Physics, 56:2, 172-185 (2015).

[3] http://youtu.be/T2DXrs0OpHU

[4] L. Innocenti, L. Banchi, A. Ferraro, S. Bose, M. Paternostro, arXiv:1803.07119.

[5] S. Lloyd, M. Mohseni, P. Rebentrost, Nature Physics 10, 631 (2014).