Syllabus and Bibliography:
Quantum Machine Learning (QML) short course

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July 24-28, 2023

Course structure

- **Introduction to Quantum Computing (QC)**

  In the first session of the course we provide a general introduction to the field of Quantum Computing (QC). This introduction is based on a number of resources with a complete presentation of the techniques and goals of the field. Among these references the book [1] is the classic references. Additional material can be found in [2] and [3]. The selection of the topics aims to provide a general presentation of the potential resources available to perform QC from a Theoretical perspective. A general introduction to Quantum Machine Learning can be found in Refs [4, 5].

  For a general introduction to Adiabatic Quantum computation the review in [6] is a complete resource. The review [7] provides a detailed introduction to Measurement based QC.

  Topics covered in this session include:

  – Introduction, QC paradigms: gate-based QC, Adiabatic QC, Measurement-based QC
  – Quantum circuits, gates
  – Gate decomposition
  – Quantum Algorithms

- **Quantum Encodings**

  As a first incursion into Quantum Machine Learning, in this section we cover the different encodings available to use Quantum states to represent a dataset. A basic and general introduction is available in Chapter 4 in [8], and references therein.

  Topics covered in this session include:

  – Basis encodings
  – Superposition for basis encodings
  – Amplitude amplification
  – Search algorithm

- **Quantum Neural Networks: Variational Methods**

  Ref [9] and references therein is a complete introduction to Variational Methods for QC by some of the original authors. Also, Chapter 5 in [8] offers a detailed discussion of the methodology and potential uses.

  Topics covered in this session include:

  – Variational eigensolvers
  – Adapt-VQE
  – Variational Methods for QML

- **Restricted Boltzman Machines (RBM)**

  Chapter 8 in [8] includes a basic introduction to RBM and their training. Also, Refs [10, 11] offer a good introduction and details about the training of RBM using Quantum annealers.

  Topics covered in this session include:

  – Training
  – Objective functions
  – Quantum RBM

- **Quantum devices based on different technologies**

  This part of the course deals with the Hardware implementations of Quantum computers in Physical systems. The approaches are diverse, using a collection of different Quantum systems to codify and process information.

  The technologies introduces in this section are:

  – Nuclear Magnetic Resonance (NMR)
  – Photonic devices
  – Ion traps
  – Superconducting circuits

  For NMR a good review is [12]. Photonic devices are introduced in detail in [13] and references therein. Quantum Computers and operations with ions are reviewed in [14]. Finally, a good introduction to QC with Superconducting circuits is [15].

References

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[2] John Preskill. Fault-tolerant quantum computation, 1997.

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[4] Peter Wittek. *Quantum machine learning: what quantum computing means to data mining*. Academic Press, 2014.

[5] Jacob Biamonte, Peter Wittek, Nicola Pancotti, Patrick Rebentrost, Nathan Wiebe, and Seth Lloyd. Quantum machine learning. *Nature*, 549(7671):195–202, sep 2017.

[6] Tameem Albash and Daniel A. Lidar. Adiabatic quantum computation. *Rev. Mod. Phys.*, 90:015002, Jan 2018.

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[8] M. Schuld and F. Petruccione. *Machine Learning with Quantum Computers*. Quantum Science and Technology. Springer International Publishing, 2021.

[9] Jarrod R McClean, Jonathan Romero, Ryan Babbush, and Alán Aspuru-Guzik. The theory of variational hybrid quantum-classical algorithms. *New Journal of Physics*, 18(2):023023, feb 2016.

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[11] Mohammad H. Amin, Evgeny Andriyash, Jason Rolfe, Bohdan Kulchytskyy, and Roger Melko. Quantum boltzmann machine. *Phys. Rev. X*, 8:021050, May 2018.

[12] L. M. K. Vandersypen and I. L. Chuang. Nmr techniques for quantum control and computation. *Rev. Mod. Phys.*, 76:1037–1069, Jan 2005.

[13] Sergei Slussarenko and Geoff J Pryde. Photonic quantum information processing: A concise review. *Applied Physics Reviews*, 6(4), 2019.

[14] C. Monroe, W. C. Campbell, L.-M. Duan, Z.-X. Gong, A. V. Gorshkov, P. W. Hess, R. Islam, K. Kim, N. M. Linke, G. Pagano, P. Richerme, C. Senko, and N. Y. Yao. Programmable quantum simulations of spin systems with trapped ions. *Rev. Mod. Phys.*, 93:025001, Apr 2021.

[15] Alexandre Blais, Arne L. Grimsmo, S. M. Girvin, and Andreas Wallraff. Circuit quantum electrodynamics. *Rev. Mod. Phys.*, 93:025005, May 2021.