Quantum Information meets Artificial Intelligence. From foundations to applications.

The goal of the course will be to show how quantum information theory can be applied, with considerable advantages, even outside of microscopic physics and, in particular, in the field of artificial intelligence. We will show how, by drawing inspiration from quantum theory, it is possible to design particularly accurate classification algorithms. We will also show some interesting applications.

The course is not aimed solely at students of physics or computer science but also at philosophers of science with interests in the foundational aspects of quantum mechanics. The formal approach will be gradual, and all technical information will be introduced starting from the initial concepts.

The course will be exclusively in English and will be held online on the Zoom platform (link: https://tum-conf.zoom-x.de/j/2627115276?pwd=aXJsZmhYem1kNDZsZDRiWUUyWjU5Zz09). The course will be interactive: during the lessons, short assignments will be given that students can complete from their own computers. For this reason, it is advisable to follow the course from a PC (and not from a tablet or smartphone). The final exam will consist of a written test that will be held in person.

This course is sponsored by Prof. Dr. Roberto Giuntini in the frame of the Philosopher in Residence fellowship.

Contact: giuseppe.sergioli@gmail.com

SCHEDULE OF THE COURSE

Lesson 1: April 18th (Thursday) 11.00-13.00
Overview of the course. Historical introduction to big data and quantum computation. Why the connection between big data and machine learning?

Lesson 2: April 24th (Wednesday) 11.00-13.00
Quantum structures. Quantum states. Pure and mixed states. Factorizable, separable and entangled states: a mathematical description. Tensor product and matrix operations.

Lesson 3: May 2nd (Thursday) 11.00-13.00
Quantum gates, quantum circuits, quantum noise channels: a general description. Quantum teleportation protocol.

Lesson 4: May 8th (Wednesday) 11.00-13.00
Brief introduction to Artificial Intelligence. The Classification problem. Difference between supervised and unsupervised scenario. Example of classifiers. Using Python and Mathematica for machine learning.

Lesson 5: May 16th (Thursday) 11.00-13.00
The idea of Quantum Machine Learning and Quantum-inspired Machine Learning. From real vectors to quantum vectors: the encoding (feature map). The quantum centroid. Classifying via normalized trace distance. Examples.

Lesson 6: May 23rd (Thursday) 11.00-13.00
Using the rescaling. Quantum state discrimination: general setting. The Helstrom bound and the Helstrom classifier. Some application.

Lesson 7: May 29th (Wednesday) 11.00-13.00
Using tensor product. Application to biomedical context.

Lesson 8: June 5th (Wednesday) 11.00-13.00
The quantum-inspired multi-class classifier. From quantum-like to quantum; a first attempt: using IBM Quantum Experience. Discriminating entanglement. Open problems.

Lesson 9: June 13th (Thursday) 11.00-13.00
Summary of the course. Feedback of the students. Open problems.

Lesson 10: June 20th (Thursday) 11.00-13.00
Recognize concepts: a quantum semantic approach to machine learning (with Prof. R. Giuntini)

Lesson 11: June 27th (Thursday) 11.00-13.00
Student presentations on a topic of choice related to the course.

Lesson 12: July 4th (Thursday) 11.00-13.00
Simulation of the final test and final discussion.

REFERENCES
1. R. Giuntini, A.C. Granda Arango, H. Freytes, F.H. Holik, G. Sergioli (2023). "*Multi-class classification based on quantum state discrimination*". FUZZY SETS AND SYSTEMS, 467-108509. ISSN: 1872-6801, Elsevier.
2. R. Giuntini, F. Holik, D.K. Park, H. Freytes, C. Blank, G. Sergioli (2023). "*Quantum-inspired algorithm for direct multi-class classification*". APPLIED SOFT COMPUTING, 134-109956, ISSN: 1568-4946, Elsevier.
3. G. Sergioli, C. Militello, L. Rundo, L. Minafra, F. Torrisi, G. Russo, K.L. Chow, R. Giuntini (2021). "*A quantum-inspired classifier for clonogenic assay evaluations*". SCIENTIFIC REPORTS 11-2830, ISSN 2405-2322, Nature.
4, G. Sergioli (2019). "Quantum & Quantum-like machine learning. A note on similarities and differences". SOFT COMPUTING, 24, 10247-10255, ISSN: 1432-7643, Springer.
5. G. Sergioli, G. Russo, E. Santucci, A. Stefano, S.E. Torrisi, S. Palmucci, C. Vancheri, R. Giuntini (2018). "*Quantum-inspired minimum distance Classification in Biomedical Context*". INTERNATIONAL JOURNAL OF QUANTUM INFORMATION, 16-8, ISSN:0219-7499, World Scientific.
6. G. Sergioli, R. Giuntini, H. Freytes (2019). "*A new Quantum Approach to binary Classification*". PLoS ONE, 14(5): e0216224, ISSN:1932-6203.

Giuseppe Sergioli is Full Professor of Logic and Philosophy of Science at the University of Cagliari, where he currently also is Coordinator of the Doctoral Advisor Council. He has been visiting scholar at Indiana University – Bloomington. He has been (and continues to be) scientific coordinator of numerous local and national research projects and he is member of various national and international scientific societies. He is the author of over 80 scientific publications in prestigious international journals in the fields of theoretical physics, foundations of physics, formal logic,

information theory, computational theory, and machine learning. His primary research interests include foundations of quantum mechanics, quantum information theory, quantum computational logic and quantum machine learning. He attended, also as invited, and organized more than 80 national and international conferences.