II years admission exam

UniPd - National PhD in fundamental technology for physics and astrophysics

Curriculum: computing and IT systems

Host University: University of Cagliari

Supervisor: Andrea Contu
Cosupervisor: Pierluigi Bortignon, Diego Reforgiato Recupero

Robert Panai - 12/09/2024

Table of contents

Research topics

Curriculum: computing and IT systems

- Goals of my PhD research: development and test of code to boost pipelines for gravitational waves research

- Planning:

  -1st year: study of machine learning and quantum computing techniques with potential applications to gravitational wave physics. Development and testing of ML and QC algorithms on local and cloud servers.

  -2nd year: application of the QC algorithms developed and tested during the first year. Work on a robust gravitational wave search pipeline (CWBurst) to create the core of the thesis. Six months abroad (to be decided soon).

  -3rd year: completion of the research developed in the first two years and writing of the thesis.

Courses and schools

1st year

Courses:

- Machine Learning for Physics
- Advanced and scientific computing in Matlab

Schools and workshops:

- Workshop sul calcolo INFN - Palau - 20-24/05/2024
- ET scienza e tecnologia in Italia - Assisi - 20-23/02/2024

2nd year

- Machine Learning programming in Physics
- Complex networks: Big Data modeling and learning

1st year research activities

Quantum Computing

- Goal: explore the potential of quantum computing and its possible applications to gravitational wave data analysis

- Results: development of gates and circuits for data manipulation in quantum computing (superposition rotational gate and long common substring gate). Test of this gates on IBM Eagle superconducting quantum computers and H2 Quantinuum Neutral Atoms quantum computer

1st year research activities

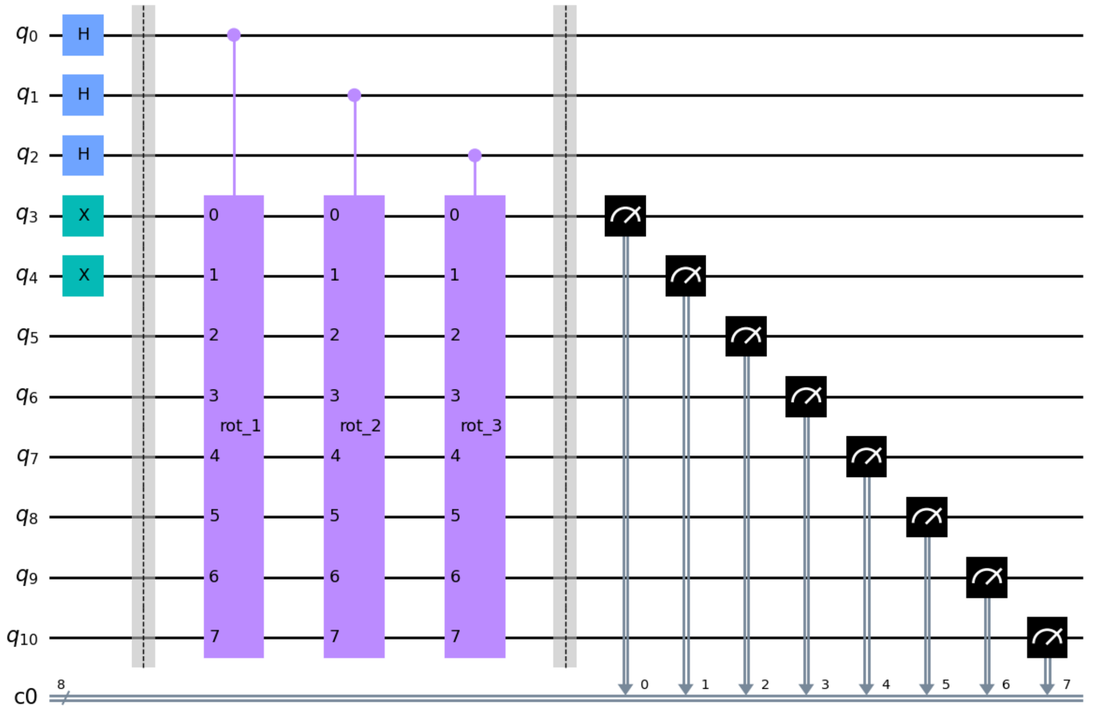
Example: controlled quantum superposition rotational gate

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$H|0\rangle = \frac{1}{\sqrt{2}} \left(|0\rangle + |1\rangle \right)$$

$$H|1\rangle = \frac{1}{\sqrt{2}} \left(|0\rangle - |1\rangle \right)$$

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$



Noiseless simulation vs real quantum computers

Example: controlled quantum superposition rotational gate

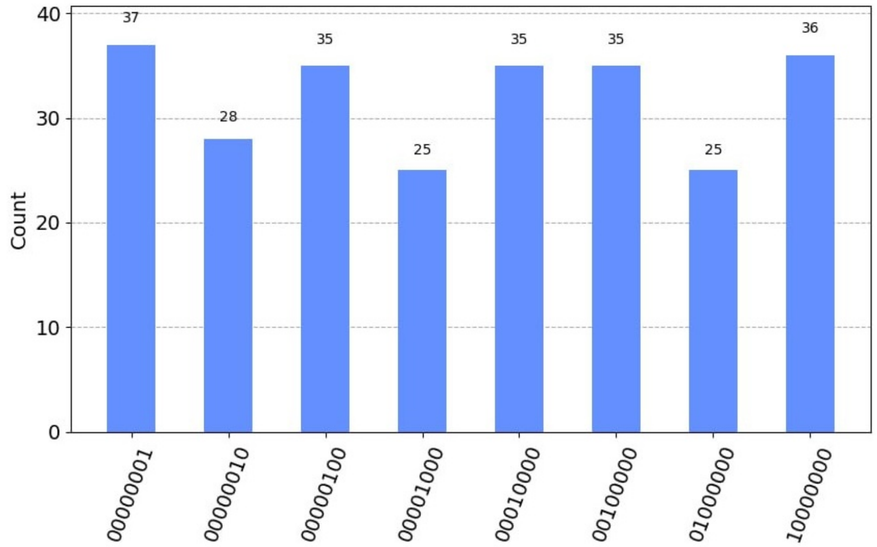
Problems: quantum decoerhence, readout and thermal noise in real quantum computers

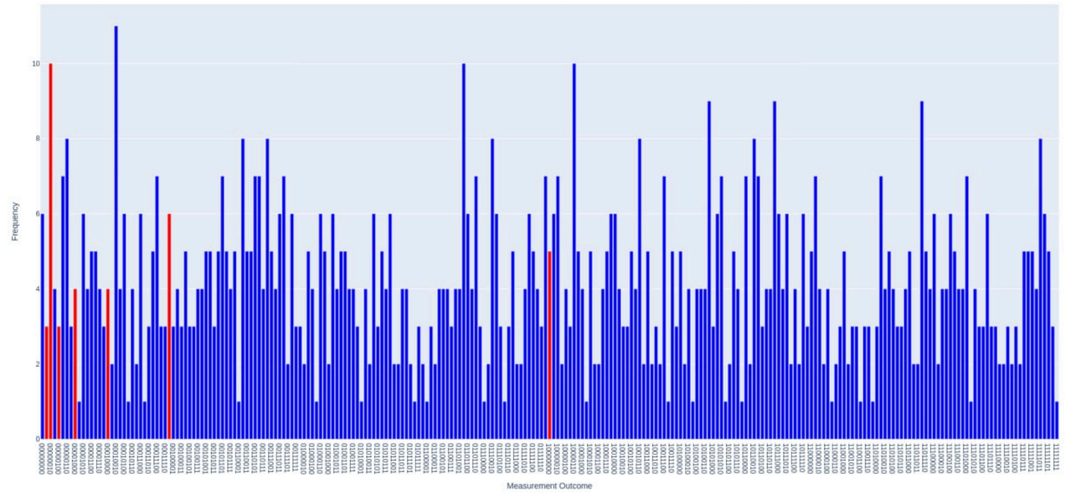
Possible solution: Quantum error correction, Neutral atoms quantum computers (for direct connectivity between qbits)

Next steps: test on H2 Quantinumm (NA QC)

-> Paper in preparation!

Goal: apply and explore applications in the world of quantum machine learning for gw research





1st year research activities

Machine learning and normalizing flow models

A normalizing flow is a machine learning model that transforms a simple probability distribution (like a Gaussian) into a more complex one through a series of invertible, differentiable transformations:

$$z_K = f_K \circ f_{K-1} \circ \dots \circ f_1(z_0)$$

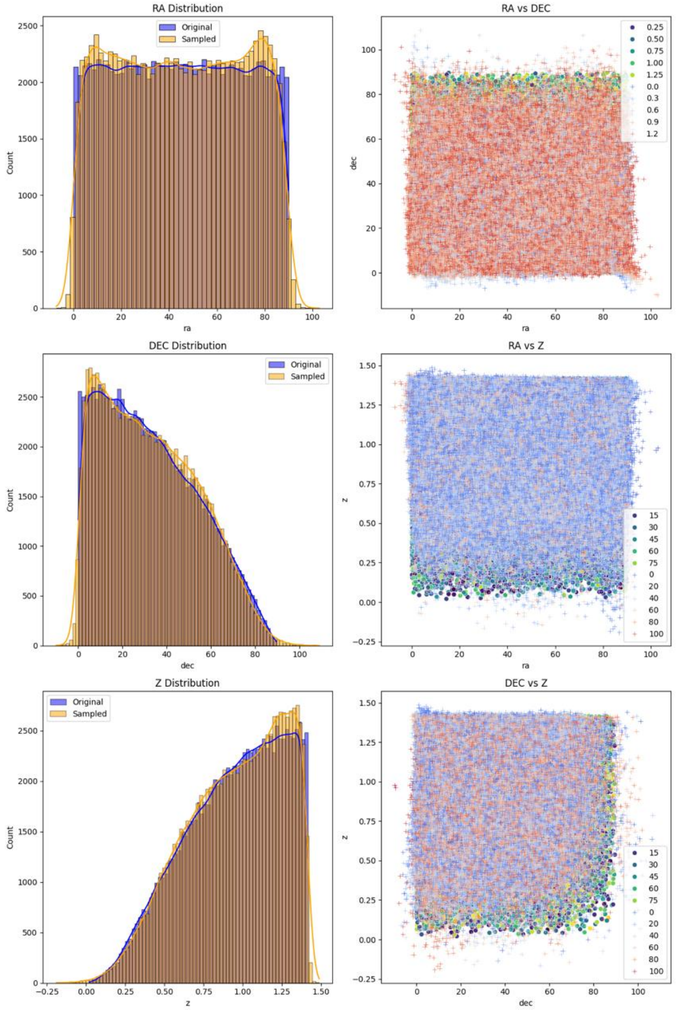
so the probability distribution is:

$$\log p(x) = \log p(z_0) - \sum_{i=1}^{K} \log \left| \det \left(\frac{\partial f_i}{\partial z_{i-1}} \right) \right|$$

1st year research activities

Machine learning and normalizing flow models

- Goal of this work: to model the probability distribution of galaxies with respect to their coordinates, redshift and a power law of their luminosity for boost some pipelines for gravitational waves inference
- Input: a.r., dec and z
- Output: $p(a\,.\,r\,.\,., dec, z, L^{\alpha})$
- Training data: Micecat catalogue



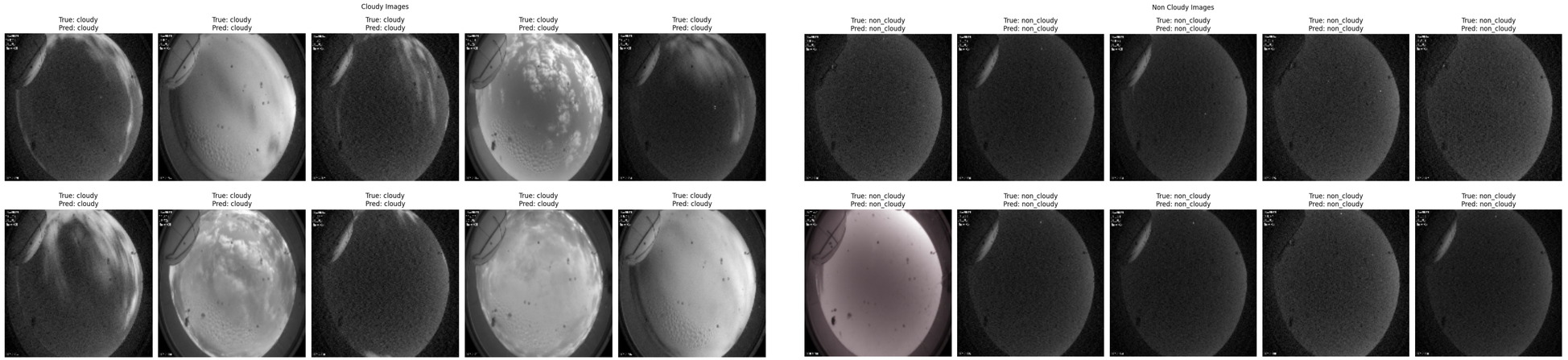
Research for the second year:

- Complete the normalizing flow model
- Explore the application of quantum machine learning to gravitational waves detection
- Start working on CWBurst

Other academic activities

Development of a CNN and an Ascom driver for astronomical dome automatization

- I have developed ASCOM drivers that allow the integration and use of any astronomical dome based on IP relay boards trough the ASCOM platform, making it possible to integrate these domes into most astronomical control software. Thanks to these drivers, the production cost of small observatories can be significantly reduced, and the flexibility of use from a SW perspective is incresead. Link to drivers: https://github.com/RobertPanai/Ascom-driver-for-IP-Clamshell-Dome/tree/main
- I have developed a convolutional neural network that monitors weather conditions using all-sky cameras. The idea is to integrate it with the ASCOM drivers for domes, so that even in the absence or malfunction of a weather station, the all-sky cameras can automatically close the dome in case of bad weather.

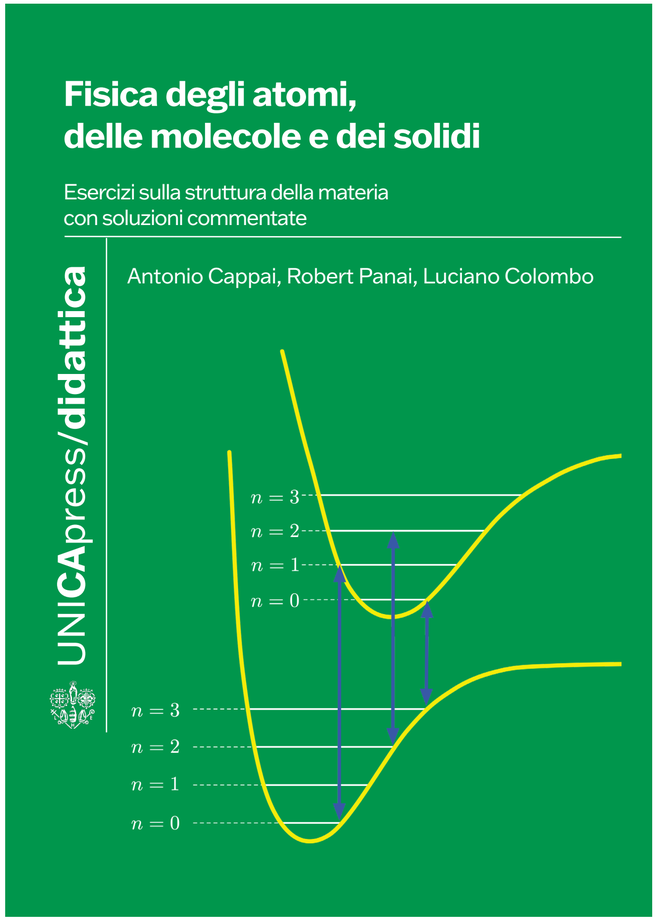


Other academics activities

Book:

- I have published a book together with Prof. Luciano Colombo and Dr. Antonio Cappai titled “Fisica degli atomi, delle molecole e dei solidi: esercizi con soluzione commentata” for the UniCa Press publishing house, available in both print and eBook at the following link:

  https://unicapress.unica.it/index.php/unicapress/catalog/book/978-88-3312-117-8



Thank you for the attention!