NeMoQC
Neuromorphic Quantum Computing

We implement concepts of neuromorphic quantum computing for optimisation and prediction tasks with use cases from aerodynamics and aeroelastics

- Applications
- Optimisation

Motivation

Concepts of neuromorphic computing (NC) appear to have the potential to make predictions and optimisations better and more efficient. A common approach for NC is Reservoir Computing (RC) or Extreme Learning Machines (ELMs), which involves stimulating some dynamical (physical) system, and probing its response, allowing our input features to be processed by natural system dynamics. This response is then decoded by a single trainable linear layer yielding an efficient, low-resource machine learning method. By considering a sufficiently correlated quantum system as the dynamical system, we can access an exponentially large Hilbert space for feature processing and avoid costly trainable quantum operations. This is usually referred to as Quantum RC (QRC) or Quantum ELMs (QELM).

Challenges

If we consider qubit quantum systems, QRC only needs a practically reasonable number of qubits to have a comparable performance to classical methods. Nevertheless, for a given use case, the main challenges tackled in this project are:

- How to optimise the QRC setup such that the minimum amount of resources are allocated?
- What quantum system should be used?
- Where to observe on the exponentially large Hilbert space offered by the correlated quantum system?
- How to implement QRC on Noisy Intermediate Scale Quantum (NISQ) devices?

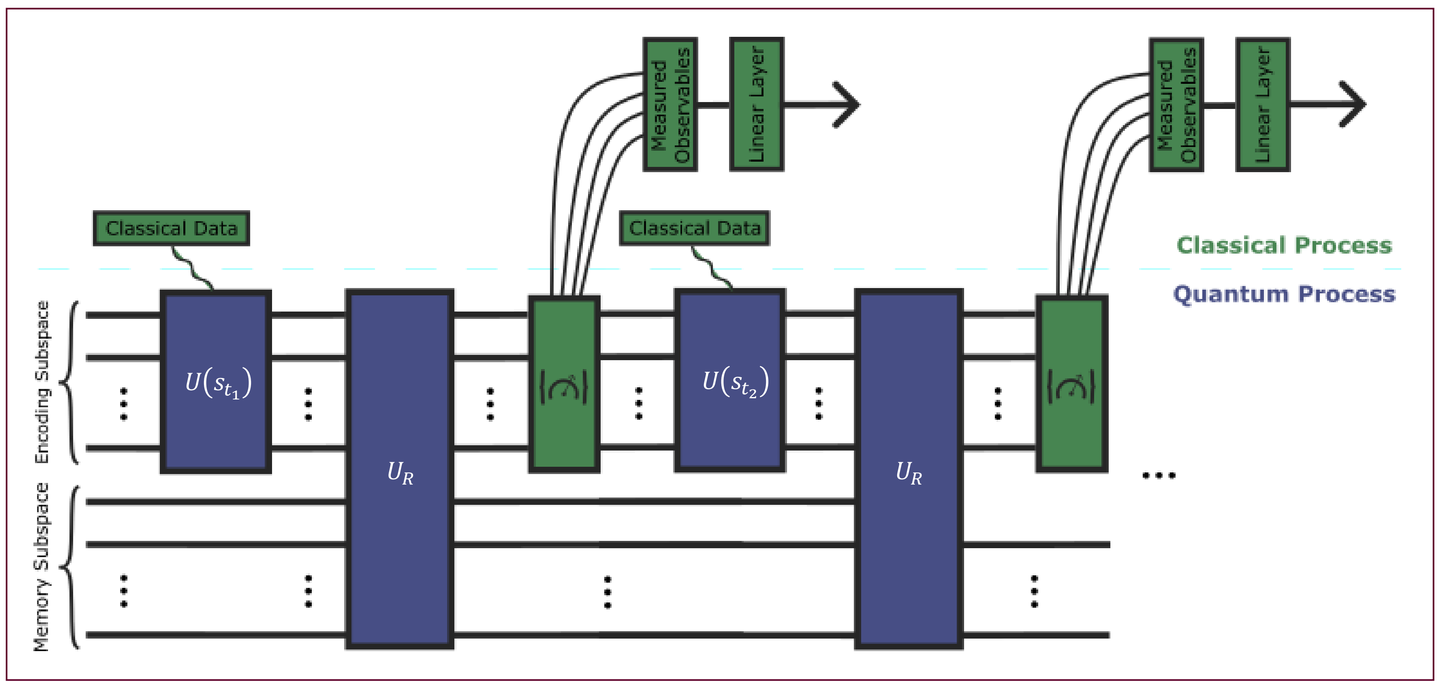

Figure 1 – Circuit-like representation of the QRC pipeline for sequence processing.

Hardware Realizations

Given that QRC does not require a large quantum system, research can already be addressed through realistic simulations and experiments on Noisy Intermediate Scale Quantum (NISQ) devices.
A wide variety of different quantum systems have been evaluated during the creation of our hardware realization roadmap. The roadmap includes also requirements on the experimental methods required for QRC.
This knowledge has been used to identify hardware candidates from the available Quantum Hardware @ QCI that will be tested as a quantum reservoir. We are investigating:

- Neutral Atoms
- Quantum Analog Computers
- Molecular quantum computers
- Other gate based approaches

Figure 4 – We are working with PlanQC to apply QRC on the Neutral Atom Quantum Computer developed in DiNAQC. Source: https://www.planqc.eu

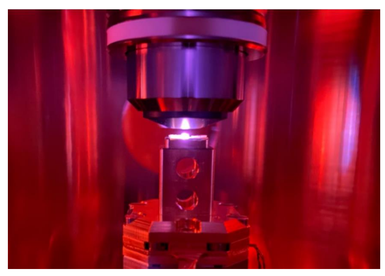

Figure 5 – We are also discussing with Nvision possible QRC implementations on an Organic Molecule Quantum Computer developed in the context of COMIQC. Source: https://www.nvision-imaging.com/

Analysis and Optimisation of QRCs

In this project, we have made progress in understanding the three main components of QRC and QELM and how they influence each other:

- Encoding – Set of non-linearities that provide the basis functions.
- Observables – Selection of the appropriate basis functions for the task.
- Reservoir Unitary U_R - Can provide memory if needed for the task but also additional expressivity.

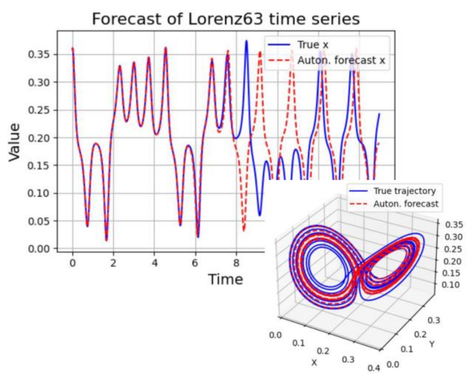

Figure 2 – Prediction of the 3 dimensional Lorenz 63 dynamical system using QRC.

Aeroelastic and Aerodynamic Time Series Prediction

Current simulation models for unsteady aerodynamics are computationally heavy, speacially for high accuracy simulations. QRC can be used as a surrogate aerodynamical model for predicting important quantities. In this project, we are making progress towards predicting lift and pitching moment given periodic sinusoidal gusts using QRC.

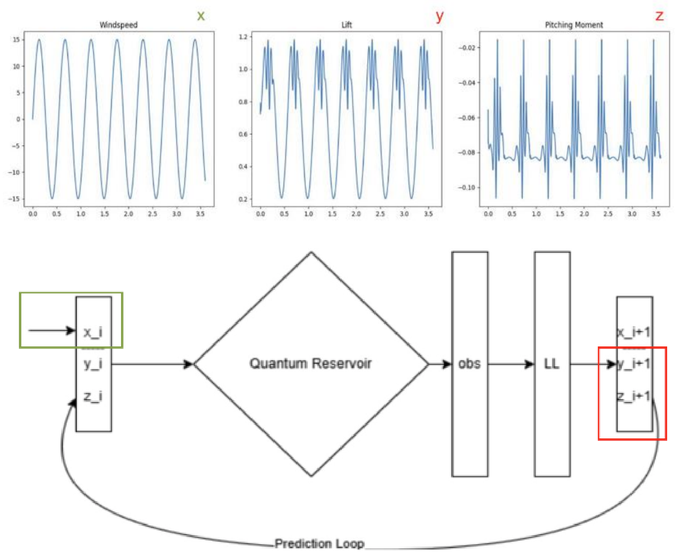

Figure 3 – Method of prediction-inference using QRC where the wind speed is used to predict lift and pitching moment.

Industry Collaboration

Within the industry collaboration, we are enhancing our expertise on QRC methods with the unique experience our partners have.
Topics we are collaborating on include:

- Implementations of QELM on realistic simulators and real quantum hardware, in particular PlanQC's neutral atom ansatz and their computer provided through QCI.
- Improvement of the current understanding and optimisations on QRC and QELM.
- Realistic application data for aeroelastic use cases is provided by Airbus.

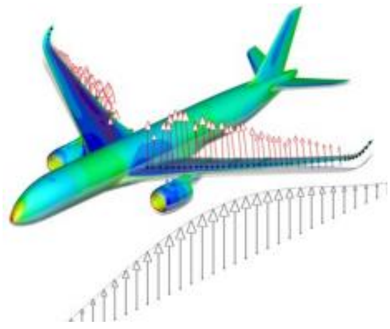

Figure 6 – Representative image of the aerodynamical behavior we want to study with data provided by AIRBUS.

A project of

DLR Institute for AI Safety and Security
DLR Institute of Aeroelasticity

Contractor

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Get in touch.
We enable quantum!