Photonic quantum memristor networks

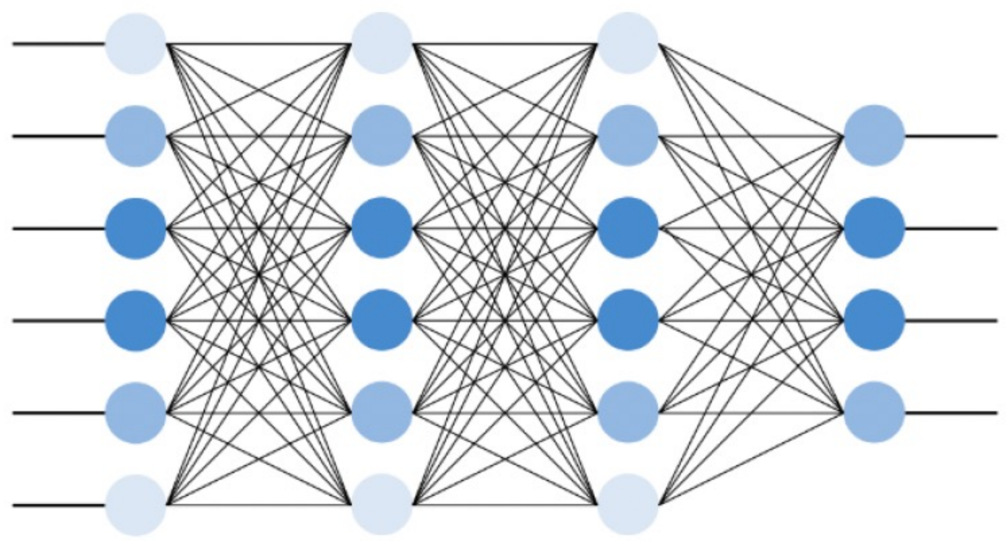
UNIVERSITY OF WARSAW
universität wien

Prof. P. Walther (UNIVIE) (PI)
Dr. Iris Agresti (UNIVIE) (co-PI)
Mirela Selimovic (UNIVIE)

Prof. M. Stobinska (UW) (PI)
Prof. R. Osellame (CNR) (PI)

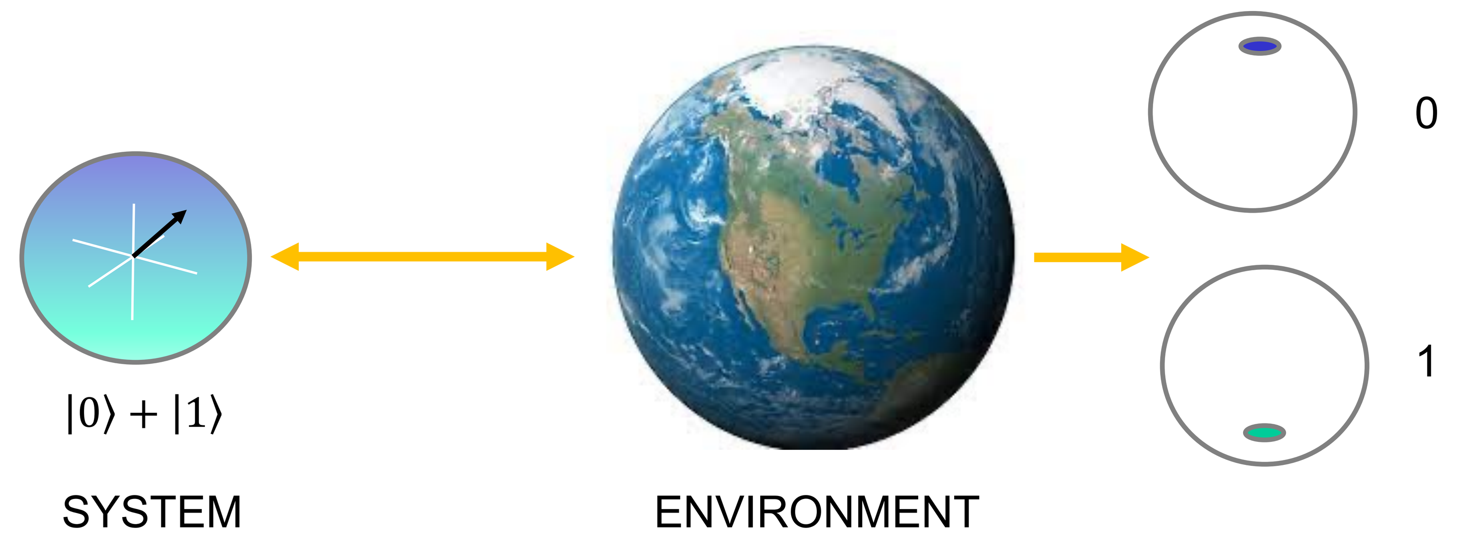
Consiglio Nazionale delle Ricerche
QUANTERA

Can we realize a quantum neural network?



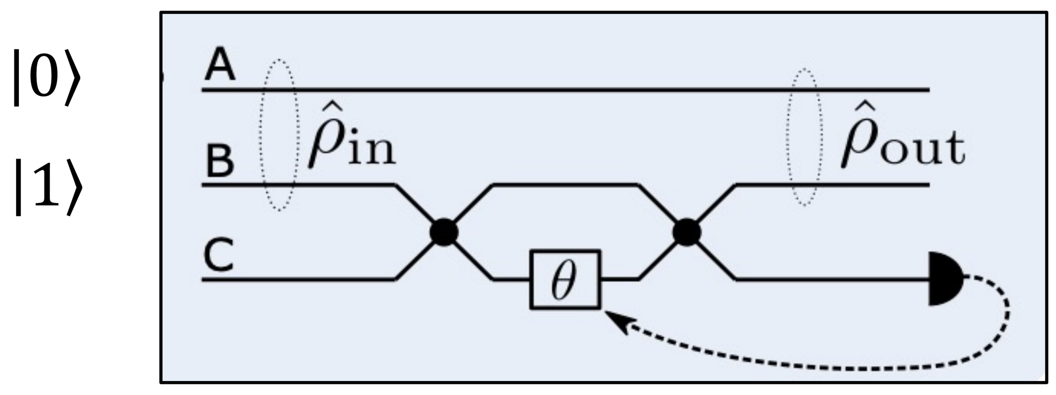
Artificial neural networks are a highly versatile machine learning model.
The learning process requires **nonlinearities**.

Closed **quantum systems** have a **linear** evolution.



Interactions with the environment bring nonlinearities but cause **decoherence**.

Nonlinear photonic element?



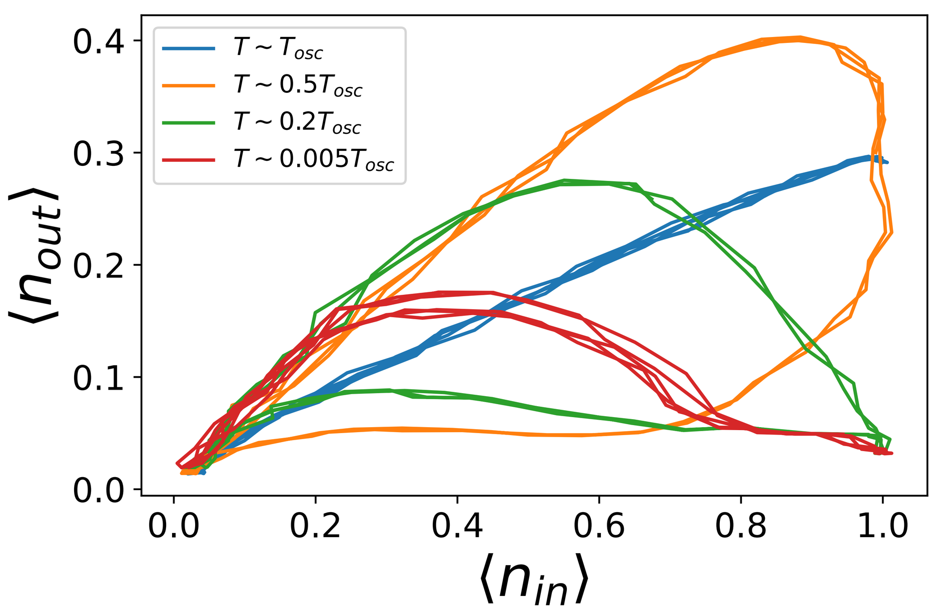
$$|\psi\rangle_{in} = \alpha(t)|0\rangle + \beta(t)|1\rangle$$

$$|\psi\rangle_{out,C} = \frac{\alpha(t)}{\sqrt{N}}|0\rangle + \frac{\beta(t)\sqrt{1-R(t)}}{\sqrt{N}}|1\rangle$$

$$R(t) = 0.5 + \frac{1}{T}\int_{t-T}^{t} \langle n_{in}(t)\rangle - 0.5\,\langle n\rangle_{max}$$

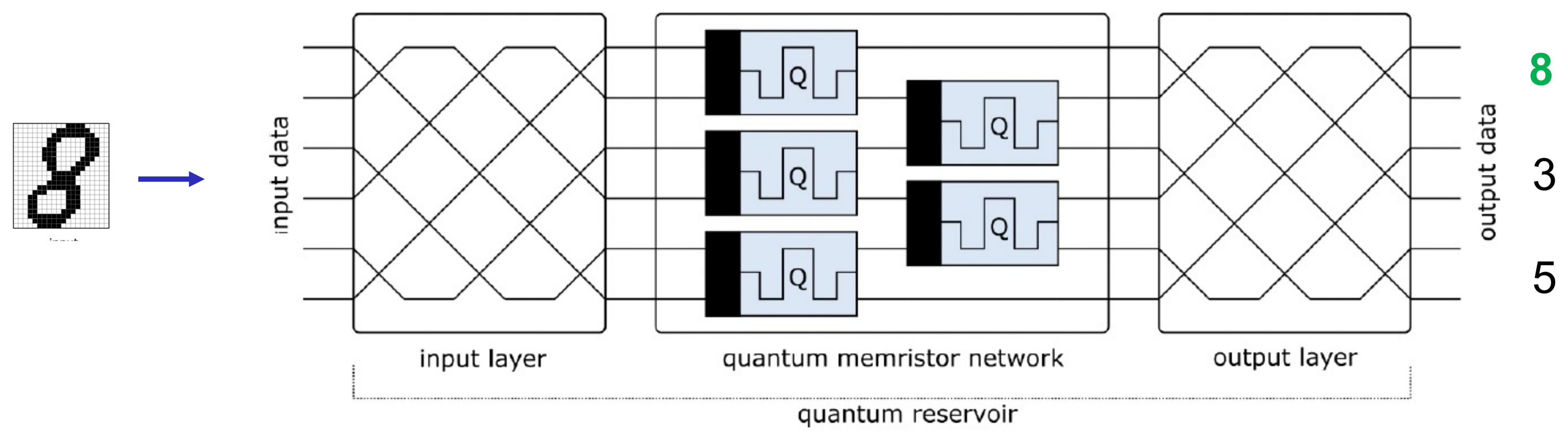
$$Tr(\rho_{out}^2) = 1 - 2|\beta(t)|^4 R(t)\big(1-R(t)\big) \neq 0$$

$$\beta(t) = \sin(\frac{\pi}{T_{osc}}t)$$



The quantum memristor displays a **nonlinear behaviour** and **short-term memory**, preserving quantum coherence[1].

PHOMEMTOR aims to combine artificial neural networks and quantum computation.

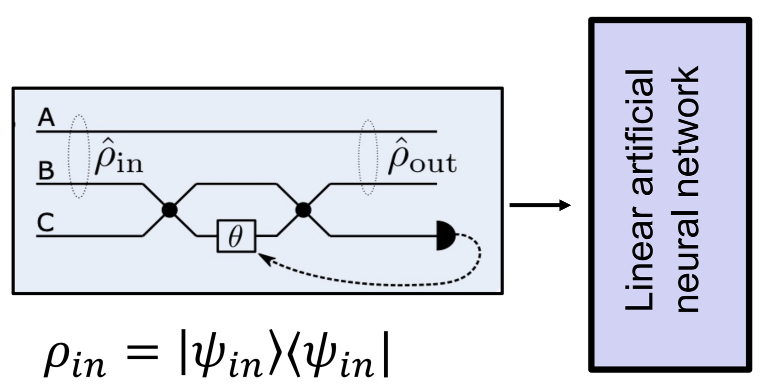


The goal is implementing a **quantum neural network**, whose nonlinearity is given by quantum memristors. This can be a building block for future **quantum neuromorphic architectures**.

Nonlinear function prediction

Given a **nonlinear function** $f(x)$ and a sequence x_1, x_2, x_3, x_4, we want our algorithm to predict the value $f(x_5)$.

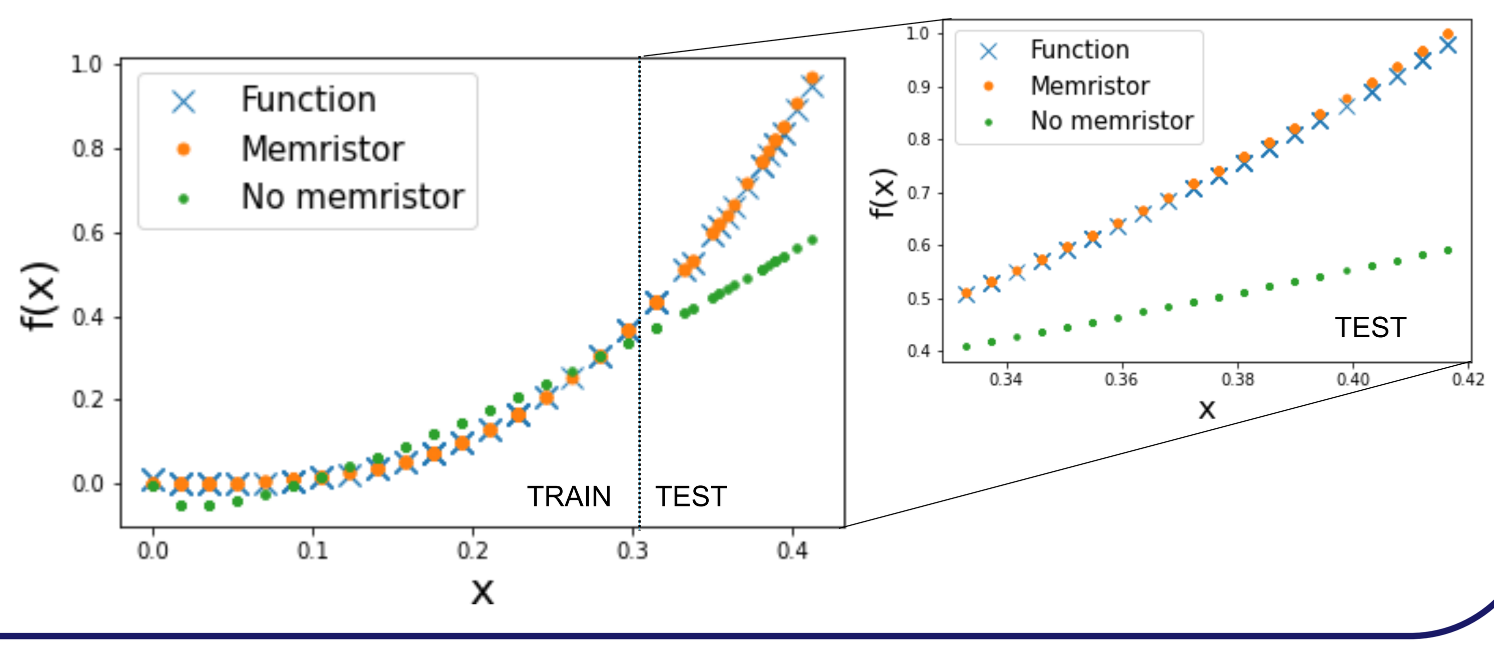
$$f(x) = x^3$$



$$\rho_{in} = |\psi_{in}\rangle\langle\psi_{in}|$$

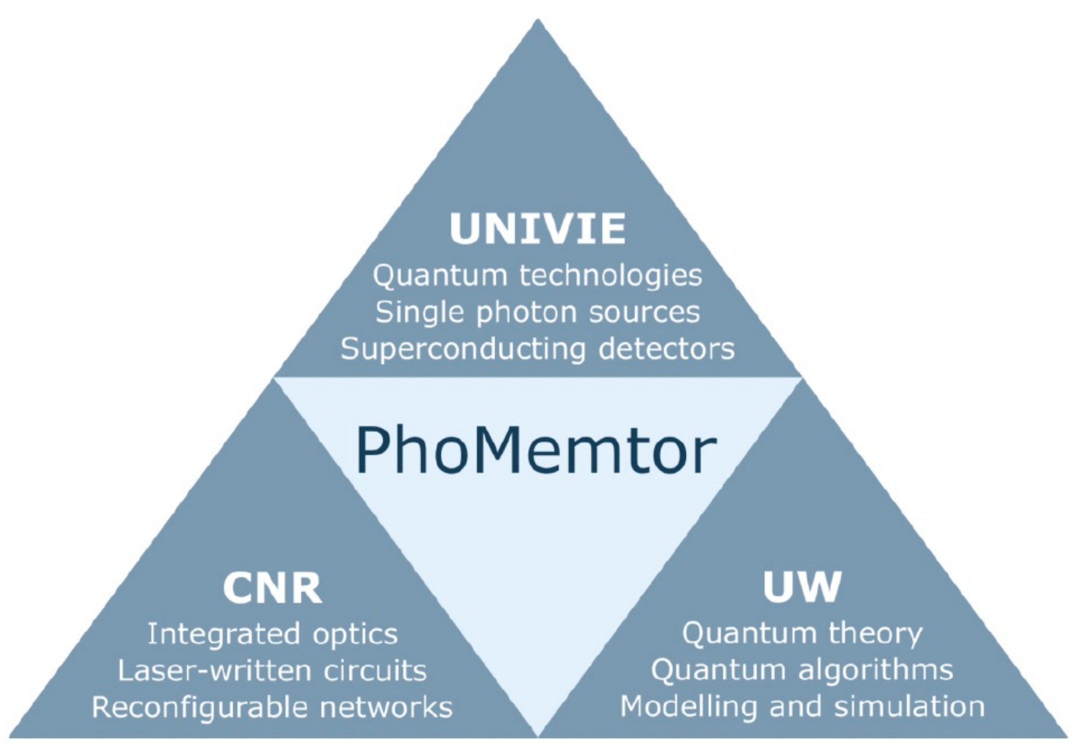
$$|\psi\rangle_{in} = \sqrt{x}|0\rangle + \sqrt{1-x}|1\rangle$$

Amplitude encoding



Perspectives and open questions

- *Scale to a larger platform, with **more nonlinear nodes** (physical and virtual, through time multiplexing)*
- ***Real world-oriented tasks** (image recognition, function approximation)*
- *Tasks with **no classical counterpart** (Entanglement detection, quantum correlation set characterization)*



1. *Spagnolo et al., Experimental quantum memristor, Nature Photonics* 16, pages 318–323 *(2022).*