Contribution ID : **67**

Type : **Poster**

Learning in a Quantum Leaky Integrate-and-Fire Neural Network under Two Relaxation Models

Leaky integrate-and-fire (LIF) neuron models are widely used in neurocomputing (Oruro et al., 2020a, 2020b). In Quantum Spiking Neural Networks (QSNNs), these dynamics can be implemented through qubit states and operations (Brand and Petruccione, 2024). However, the quantum representation of the leakage term does not necessarily reproduce the exponential decay characteristic of the membrane potential in the classical LIF model.

In this work, we propose an alternative formulation of the leakage term based on quantum relaxation, which more faithfully reproduces the exponential decay of the neuronal membrane potential. To assess whether this difference is relevant to network training, we compare two QSNN formulations: an implementation of the previously published model and our proposed formulation. Both were evaluated on image classification tasks using MNIST, Fashion-MNIST, and Kuzushiji-MNIST.

The results show that the proposed formulation does not yield a consistent improvement in classification performance, but it provides a more faithful representation of the leakage dynamics expected in an LIF neuron. These results suggest that its behavior should be further explored under realistic quantum simulations and exploited in real hardware, where physical relaxation processes may play a more relevant role.

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Session Classification : Física Teorica & simulacion