Phase-Space Framework for Quantum Optical Neural Networks

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Quantum optical neural networks (QONNs) take advantage of the combined principles of classical and quantum optics to achieve information processing capabilities that surpass classical approaches [1]. Nevertheless, simulating large-scale bosonic networks remains a substantial challenge due to the exponential expansion of the Hilbert space required for an accurate description of quantum dynamics. Consequently, previous theoretical studies have been limited to small-scale systems, leaving the behaviour of multimode QONNs unexplored. This work presents an efficient computational framework based on the phase-space positive-$\mathcal{P}$ method for simulating bosonic neuromorphic systems [2]. This approach provides a view to previously inaccessible regimes, allowing the validation of large-scale bosonic networks in various quantum machine learning tasks such. In our work we employed the QONN to discriminate between three distinct classes of quantum-optical states: Schrödinger cat states, squeezed vacuum states, and coherent states. Due to the highly nontrivial response of the reservoir network to excitation by different states presented schematically, we were able to achieve classification accuracy of 93%. Moreover, we studied the dependence of this accuracy on the network size and inherent Kerr-like nonlinearity. Our results show that the performance of a large quantum reservoir does not improve monotonously with the number of bosonic modes, instead following a complex dependence driven by the interplay of nonlinearity, reservoir size, and the average occupation of the input mode. A similar behavior has been found for the task of quantum state feature prediction, a regression task where the complex squeezing parameter of a squeezed vacuum state has been predicted. These findings are essential for designing and optimising optical bosonic reservoirs for future quantum neuromorphic computing devices.

References

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