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Quantum Reservoir Learning on Pasqal neutral-atom Quantum Computer

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The rapid progress in quantum technologies and the advent of Noisy Intermediate-Scale Quantum (NISQ) devices have inaugurated a new computational paradigm. Concurrently, Artificial Intelligence continues to drive transformative advances across research and industry. Recent studies have demonstrated that the integration of these two paradigms can yield mutual benefits, fostering the exploration of hybrid quantum-classical schemes to mitigate the inherent limitations of current quantum hardware. Among the most extensively investigated approaches are Variational Quantum Algorithms (VQAs), which exploit the complementary capabilities of quantum and classical processors through variational optimization. Despite their early success, VQAs exhibit significant scalability challenges, particularly due to convergence to local minima and the barren plateau phenomenon, which severely impairs gradient-based training.

A promising alternative is offered by Quantum Reservoir Computing (QRC), which circumvents the need for costly classical optimization by leveraging the quantum reservoir dynamics coupled with a linear classical layer. This design intrinsically avoids barren plateaus and provides an efficient framework for machine learning applications on NISQ devices. In this work, we present the implementation of a QRC pipeline on the Pasqal neutral-atom quantum platform, including both classical emulation and real-hardware execution. Developed within the Pulser-Pasqal environment, our approach encodes classical inputs into global or local detuning waveforms and extracts embeddings from quantum measurements for a supervised learning task. The obtained QRC embeddings demonstrated a robust improvement over classical baselines, achieving higher test accuracies across different data encoding strategies and using a small-scale neutral-atom setup as the quantum reservoir.

We validate the effectiveness of our implementation through systematic comparisons between different encoding schemes, assessing their impact on both model performance and computational efficiency. This analysis provides crucial insights into the optimal strategies for quantum feature extraction on current hardware. Finally, we discuss the transition from emulated to physical QPU execution, performed through Cineca's HPC infrastructure, highlighting the impact of hardware noise and shot statistics. Our results outline future directions for enhancing QRC performance on real quantum processors and demonstrate the viability of quantum machine learning on near-term quantum devices.

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