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Evaluating Quantum Convolutional Neural Networks for Transient Gamma-Ray Burst Signal Detection

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Quantum Machine Learning (QML) merges Quantum Computing with Machine Learning to address complex problems in various scientific fields, including Astrophysics. Astrophysics, with its reliance on extensive datasets from terrestrial and satellite observations, demands rapid and precise methodologies for data analysis. Deep Learning (DL) has increasingly been applied to tackle astrophysical challenges, yet the potential of Quantum Deep Learning (QDL) remains underexplored.

This study focuses on the performance of Quantum Convolutional Neural Networks (QCNNs) in detecting transient Gamma-Ray Bursts (GRBs), which are intense, brief gamma-ray flashes originating from cosmological events. GRBs are categorized into short-duration bursts, resulting from neutron star mergers, and long-duration bursts, caused by the collapse of massive stars.

Building on prior work (Rizzo et al. 2024) demonstrating QCNNs' effectiveness in identifying GRBs in AGILE mission data, we expanded our analysis to include simulations from the Cherenkov Telescope Array (CTA). The CTA represents the next generation of ground-based observatories for high and very-high energy gamma-ray science, featuring advanced, sensitive telescopes and real-time data analysis capabilities crucial for immediate GRB detection and alert generation.

We employed hybrid quantum-classical machine learning techniques, using Parametrized Quantum Circuits, and evaluated the QCNN performance through both Pennylane and Qiskit libraries. Various architectures and encoding strategies, including Data Reuploading and Angle and Amplitude encoding, were explored.

Our comparative analysis with classical CNNs revealed that QCNNs achieved comparable accuracy (over 90%) with fewer parameters, although they did not yet surpass classical methods in terms of training time, due to the nascent state of quantum deep learning optimizations.

As the first exploration of QCNNs in astrophysical applications, this research highlights the potential, benefits, and current limitations of integrating quantum approaches in astrophysics, paving the way for future advancements in the field.

Title

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