A Machine-Learning Driven Approach to Detecting Gravitational Wave Signals From LIGO

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Gravitational waves (GWs) are ripples in spacetime produced by massive astronomical events such as compact binary coalescences (CBCs) involving black holes and neutron stars. Although matched filtering pipelines remain the standard detection method, they face challenges in high-noise environments and require large template banks. This project investigates the application of a one-dimensional Residual Convolutional Neural Network (1D ResNet CNN) as a scalable, efficient alternative for classification of GW signals embedded in detector noise. Synthetic black hole, neutron star, and hybrid (NS/BH) waveforms were generated using the PyCBC library, employing a curriculum learning strategy and signal-to-noise ratio (SNR) rescaling to train the model across a realistic range of signal strengths, including sub-threshold signals below the standard LIGO detection boundary. The model achieved a peak validation AUC of 0.8886 with validation accuracy at 74-76%, evaluated under a difficult class distribution reflecting realistic operational conditions. The trained model was subsequently applied to real strain data from confirmed LIGO events (GW150914, GW170817, and GW190521) and benchmarked against a matched filter implementation on equivalent synthetic test data. The CNN approached matched filter performance at moderate-to-high SNR while processing samples at substantially lower computational cost, exhibiting near-optimal discrimination without exhaustive template bank searches. These results position the CNN as a viable rapid pre-screening stage within a hybrid detection pipeline, demonstrating that deep learning represents a practical and scientifically meaningful complement to conventional GW detection, with implications for real-time, multi-messenger astronomy.

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