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Deep Learning Models to Analyze Gamma-ray Images and Time Series for Space and Ground-Based High-Energy Facilities.

Friday, 11 October 2024 11:30 (30 minutes)

In this contribution, we present several Deep Learning (DL) models developed for high-energy astrophysics to detect and localize gamma-ray transient sources, such as gamma-ray bursts (GRBs). These models were applied to high-energy projects including AGILE, COSI, and CTAO.

AGILE is a high-energy astrophysics space mission launched in 2007, which concluded operations in 2024. Its payload includes, among others, the Gamma-Ray Imaging Detector (GRID) and an Anti-Coincidence System (ACS). We developed the first DL-based method to detect and localize GRBs in the GRID sky maps above 100 MeV, successfully detecting 21 GRBs in the AGILE archive. Additionally, we implemented a method using anomaly detection on time series data generated by AGILE/ACS (50-200 keV), which detected 72 GRBs, including 15 new detections in AGILE data. The final model for AGILE uses a deep neural network to predict the expected background count rates of the ACS based on the satellite's orbital and attitude parameters. By comparing the predicted and acquired count rates, the model detected 39 GRBs, four of which are new to the AGILE data. We calculated the p-value distribution for all DL models to evaluate the statistical significance of the detected GRBs.

From the knowledge gained with AGILE, we are also developing a DL model for the COSI soft gamma-ray survey telescope (0.2-5 MeV) to localize GRBs using the count rates of the BGO shield panels. Localization can be further improved by including the count rates of the germanium detectors.

The Cherenkov Telescope Array Observatory (CTAO) aims to advance ground-based very-high-energy gamma-ray astronomy, featuring the Science Alert Generation (SAG) system as part of the Array Control and Acquisition (ACADA) system. We developed an anomaly detection autoencoder to improve the CTAO capability of detecting GRBs in real time, using energy-dependent light curves as multi-variant time series data. This DL model aims to achieve faster detections without a minimum photon count as constrained by standard analysis. Additionally, we developed two Convolutional Neural Network (CNN) prototypes to enhance the scientific analysis of CTAO data in real-time: an autoencoder for subtracting background noise from observation counts maps and a regressor for extracting the coordinates of the brightest source. Using the current ACADA/SAG pipelines as a reference, the autoencoder showed a minimal source count loss with a mean difference of about 2 counts (± 8 at the 1σ level), while regressor tests indicated a 68% containment radius 0.07° compared to the of 0.04° achieved with the current standard analysis. Both CNN models, though, operate without prior knowledge of target position, background templates, or instrument response functions (IRFs), opposite to the standard analysis.

Finally, we are developing Quantum Deep Learning (QDL) models to compare them with classical models. The goal is to explore how quantum computing features can enhance the training process and improve results obtained with DL models.

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