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Onboard machine learning for high-energy observatories for spacecraft autonomy and ground segment operations

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Machine Learning (ML) techniques have proven highly effective in gamma-ray data analysis performed in ground-based pipelines. Implementing ML analysis directly onboard satellites introduces transformative capabilities that enhance both spacecraft autonomy and ground segment efficiency. Onboard ML processing significantly reduces the required downlink bandwidth by selecting relevant data before transmission, minimizing operational costs and improving the scientific return of gamma-ray observatories. Additionally, real-time ML-based event classification enables rapid decision-making onboard, allowing instruments to autonomously prioritize and respond to transient astrophysical phenomena such as gamma-ray bursts (GRBs) and gravitational wave counterparts without relying on ground-based intervention.
This shift from centralized to decentralized data processing also has important implications for the role of the ground segment in space missions. By enabling spacecraft to autonomously filter and analyze scientific data, onboard ML reduces the workload on ground operators and optimizes the use of limited communication bandwidth. The growing availability of commercial off-the-shelf (COTS) edge computing devices equipped with AI accelerators facilitates the deployment of these advanced models in space environments, allowing also prototyping activities to advance in this new research field.
This contribution provides an overview of the advancements enabled by onboard ML and presents some use cases, with a focus on its application for future X- and gamma-ray observatories. Optimization techniques for neural networks, including quantization and pruning, facilitate the deployment of ML models on onboard computing platforms and can also impact ML applications for ground-based analysis by enabling more efficient use of computing resources. By integrating onboard ML capabilities with ground-segment data processing and mission control centers, it will be possible to enable autonomous, high-efficiency space science missions for high-energy astrophysics.

Eligibility for ”Best presentation for young researcher” or ”Best poster for young researcher” prize

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