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Machine Learning and Hardware Acceleration for Space-Based Detection: Particle Track Reconstruction and Low-Energy Gamma Imaging

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The Spartan and LEGIMaC projects share a common goal: advancing space-based detection technologies by integrating cutting-edge machine learning algorithms with energy-efficient hardware platforms, such as FPGAs and GPUs. Both projects address critical challenges in the reconstruction and classification of complex physical events in high-rate, noisy environments—typical of astrophysics experiments and orbital detectors.
Spartan focuses on the real-time reconstruction of particle tracks in high-density environments by training deep neural networks on both synthetic and experimental data. The approach leverages temporal information to disentangle overlapping events, enhancing accuracy in track identification. The algorithms are optimized for low-power, radiation-tollerant FPGAs, enabling their deployment in space with minimal energy consumption and high reliability.
On the other hand, LEGIMaC targets the detection of very low-energy gamma events at high rate in space calorimeters, overcoming traditional trigger limitations and the intrinsic dark noise of large-area SiPMs. By applying ML techniques to waveform shape analysis, LEGIMaC discriminates between dark counts and genuine scintillation events with longer decay constants. It also addresses the problem of event pileup in high-flux environments, allowing accurate energy reconstruction at the edge of detectability.
Both initiatives emphasize a hardware/software co-design philosophy to maximize computational efficiency, scalability, and robustness. The potential impact extends far beyond space science, with promising applications in nuclear medicine, security systems, and high-energy physics. Together, Spartan and LEGIMaC represent a major step toward the development of a new generation of intelligent, space-ready detection systems capable of operating in the most challenging conditions.

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