The ISOLDE Space Demonstrator: A Platform for AI Applications on Satellites

RISC-V in Space Workshop 2025

Antonio Sciarappa, Emanuele Valpreda, Roberto Morelli (Leonardo), Davide Di Ienno (Thales Alenia Space Italia)

Carlo Ciancarelli, Paolo Serri, Valeria Parascandolo, Antonio Leboffe, Dario Pascucci (Thales Alenia Space Italia)

Daniele Gregori, Mattia Paladino (E4 Computer Engineering)

Daniele Jahier Pagliari, Alessio Burrello, Sara Vinco, Gianvito Urgese, Maurizio Martina, Guido Masera (Politecnico di Torino)

William Fornaciari, Federico Reghenzani, Andrea Galimberti, Giovanni Agosta, Davide Zoni (Politecnico di Milano)

Andrea Acquaviva, Francesco Conti (University of Bologna)

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The ISOLDE project

Overview of **ISOLDE** (KDT JU):

- **Duration**: 01.05.2023 - 30.04.2026
- **Goal:** Enhance European high-performance **RISC-V**-based System-on-a-Chip (SoC), achieving functional and non-functional (safety, security, power efficiency) improvements to compete with, or surpass, existing commercial / proprietary alternatives
- **Activities**: Development of advanced architectures, novel accelerators, and reusable IPs, forming a robust compute infrastructure that will be demonstrated on applications coming from the automotive, industrial, and **aerospace** domains
- **Partners**: About 40 partners involving large industries, small/medium enterprises, and academic from 9 different European countries, collaborating to establish European sovereignty in semiconductors, close the confidence gap, and drive adoption through prototype solutions, documentation, and benchmarks

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Space Demonstrator

Within ISOLDE, one of the Demonstrators is developed targeting **Space** satellites:

- Harness RISC-V processor, accelerators and advanced software layer to enable processing capabilities closer to the sensor and support the development of onboard inference capabilities
- Minimize uplink and downlink requirements, accelerate real-time decision-making and enhance satellite autonomy by bringing the processing steps onboard
- Create a hardware and software platform capable of satisfying the dual challenges of demanding computing / memory requirements and the harsh environmental constraints of space

The Space demonstrator targets a LEO satellite, focusing on **two applications**:

- **Hotspot detection**: AI models for hyperspectral data hotspot classification based on raw images
- **Satellite health monitoring**: ML models for anomaly detection based on telemetry data on-board

Performance of these AI algorithms will be evaluated on the new hardware, showcasing their potential to redefine the role of onboard computing in space systems

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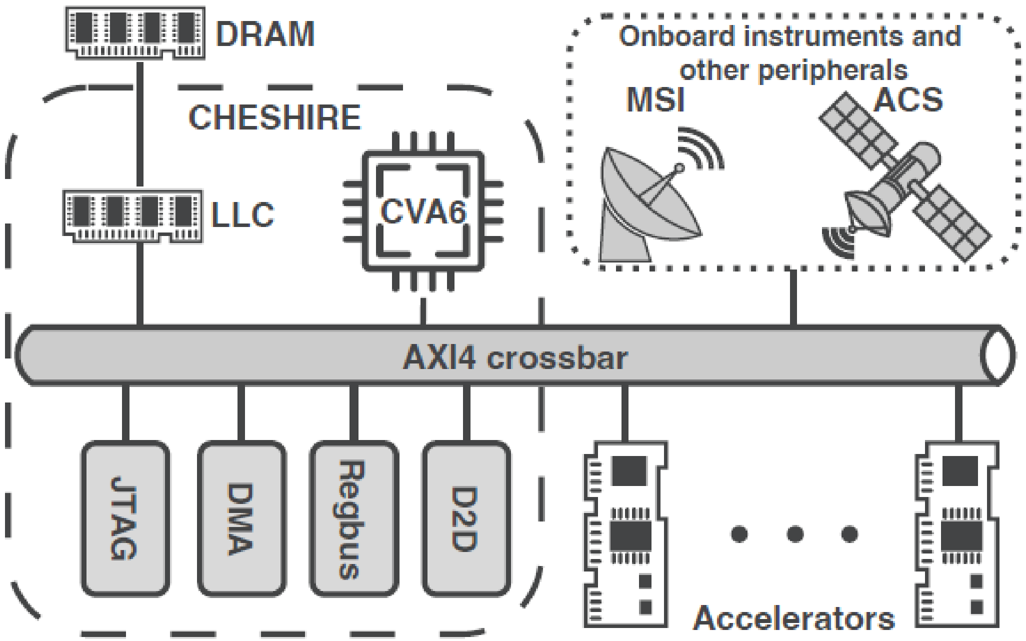
HW architecture

High-level view of the proposed system architecture:

- Linux-capable Cheshire[1] host platform (dashed line), implementing a 64-bit RV64GC CVA6 core
- AXI4 crossbar[2] connecting the core with Last-Level Cache, JTAG, DMA and other peripherals
- Reconfigurable and mixed-precision accelerators, on which compute-intensive AI workloads are offloaded (fast and energy efficient vector-vector, matrix-vector, and matrix-matrix operations)
- CVA6 core executes OS, general tasks, configures accelerators, controls peripherals; accelerators only execute compute intensive workloads and have their own DMAs and control units



[1]: "Cheshire: A lightweight, linux-capable risc-v host platform for domain-specific accelerator plug-in", A. Ottaviano, T. Benz, P. Scheffler, and L. Benini

[2]: https://docs.openhwgroup.org/projects/cva6-user manual/ 01_cva6_user/ AXI_Interface.html

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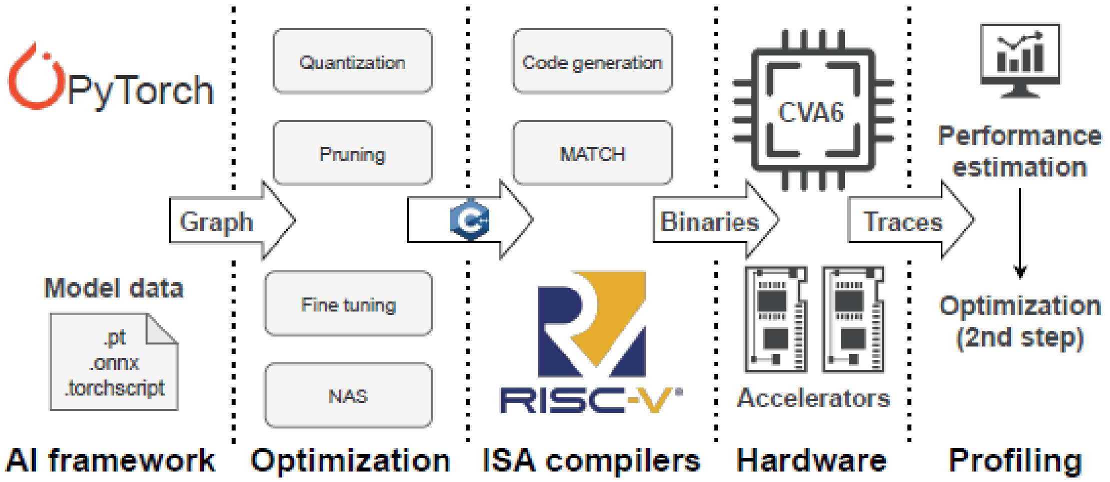
SW stack

High-level view of the SW stack (under development):

- Need HW-aware SW stack to enable automated deployment of optimized, efficient AI applications
- SW stack should allow to compress and optimize models developed with popular AI frameworks for the accelerator on which are going to be offloaded
- Quantization and pruning applied to achieve low-latency and energy-efficient edge inference
- HW aware Neural Architecture Search algorithms (e.g. Plinio[3]) to fully exploit HW accelerators
- Compressed model transformed to representation interpreted and optimized by compiler (MATCH[4])



[3]: "Plinio: a user-friendly library of gradient-based methods for complexity-aware dnn optimization", D. J. Pagliari, M. Risso, B. A. Motetti, and A. Burrello

[4]: "Match: Model aware tvm-based compilation for heterogeneous edge devices", M. A. Hamdi, F. Daghero, G. M. Sarda, J. Van Delm, A. Symons, L. Benini, M. Verhelst, D. J. Pagliari, and A. Burrello

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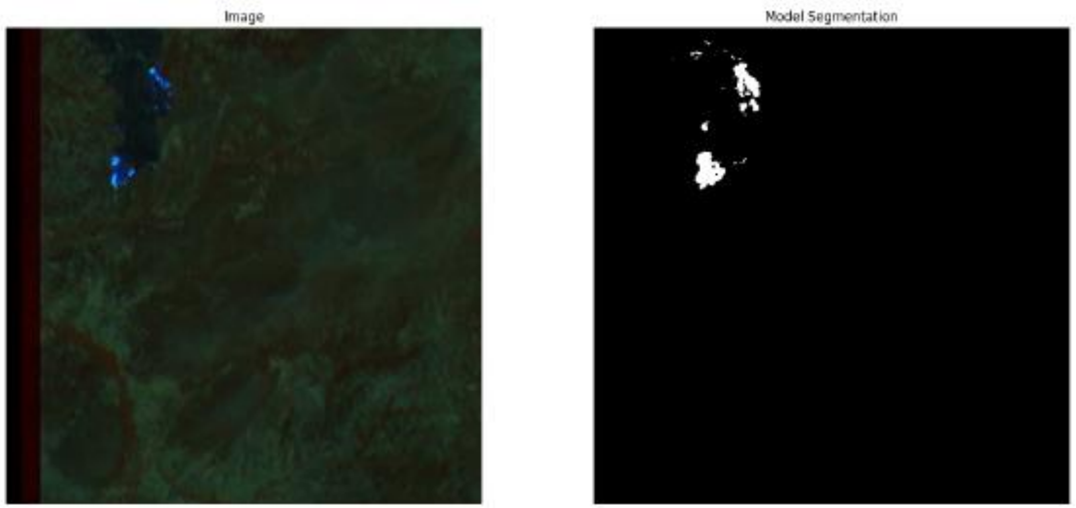
AI applications - Hotspot detection

Ai application demonstrator for Earth Observation missions: hotspot detection

- Automatic wildfire detection from multispectral satellite images, collected from Sentinel-2
- Public dataset THRawS (Thermal Hotspots in Raw Sentinel-2) with wildfire and volcano events
- Ground truth annotations indicate whether a pixel corresponds to a volcano or wildfire event
- Raw images need light coregistration preprocessing step (PyRawS), to be executed onboard



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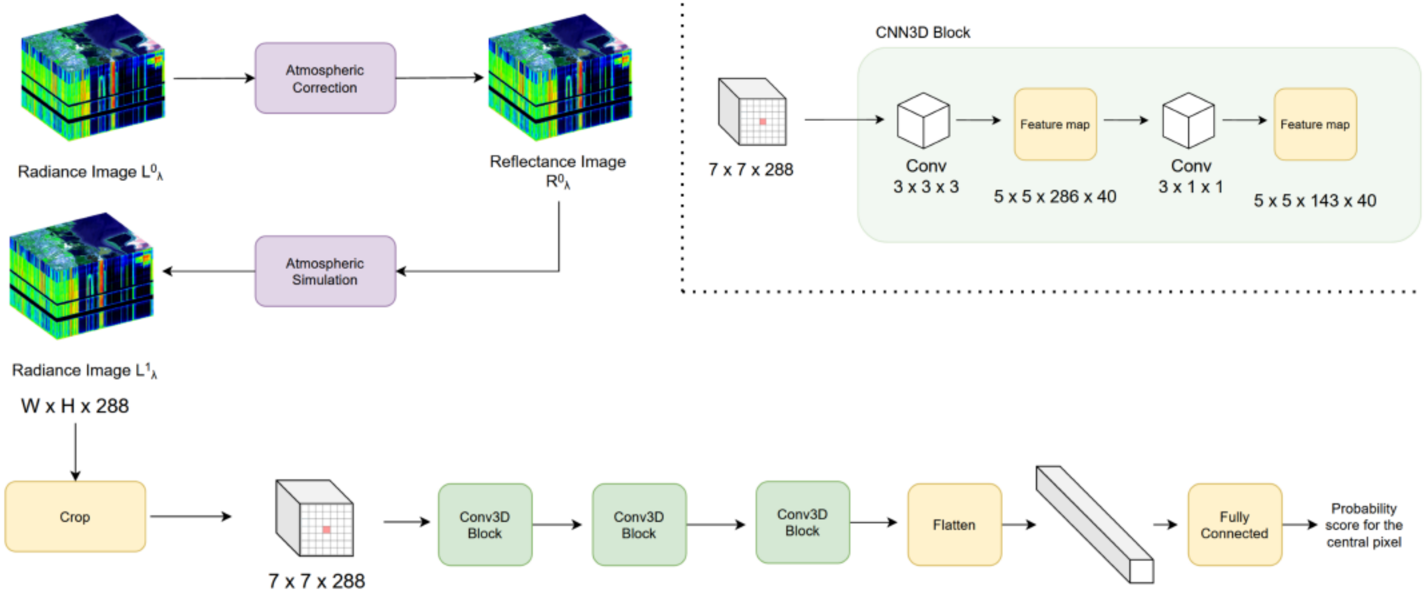
AI applications - Hotspot detection

AI model considered:

- Multispectral images cropped into 7x7 patches, central pixel classified in "fire" or "not-fire" classes
- Architecture with three 3D convolutional blocks, a flat layer and a final fully connected classification layer
- 3D convolutions capture spectral and spatial features jointly, giving more comprehensive representation



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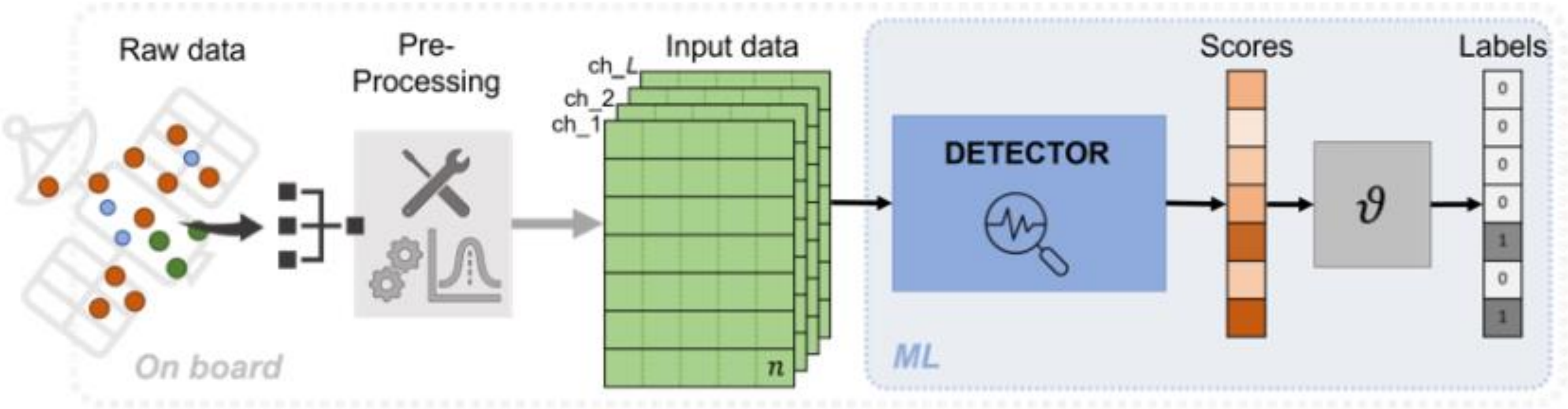
AI applications - Satellite Health Monitoring

Fault Detection methodologies:

- Critical for satellites to ensure reliability and maintain operability during the expected lifetime
- Traditional approaches require expert knowledge, significant work throughout engineering and service
- ML techniques can enable early detection of anomalies and potential faults reducing response times; approach based on ML analysis of telemetry data directly onboard the spacecraft



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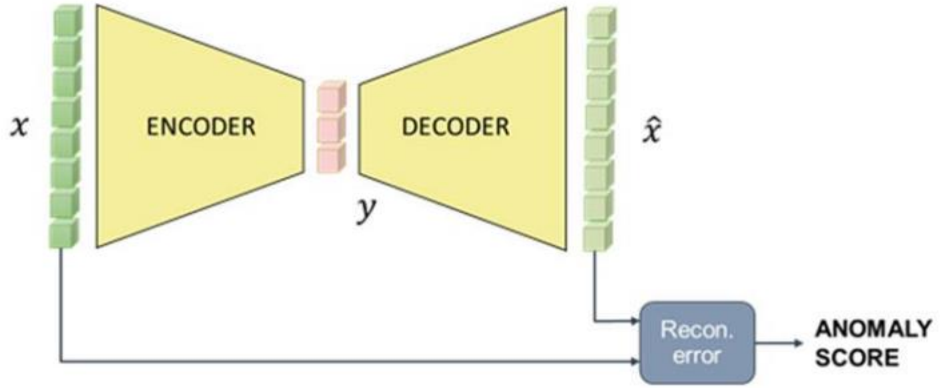
AI applications - Satellite Health Monitoring

ML techniques considered:

- Models based on convolutional autoencoders and long-term short-memory (LSTM) architectures
- Semi-supervised learning, networks trained on nominal data and validated on data with anomalies
- Data in the form of multi-variate time series from satellite subsystems, with simulated anomalies added to reduce the unbalanced dataset (usually anomalies very rare in real situations)
- Preprocessing step needed (e.g. data conversion, normalization) and should be also performed onboard



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Summary and conclusions

Recap - ISOLDE Space Demonstrator:

- Need to execute AI workloads onboard to enable autonomous satellite operations, which however comes at the cost of high computational complexity, energy consumption, and processing latency
- In ISOLDE, study to enable edge inference on a resource constrained environment by means of a joint hardware and software design approach
- Goal of the Space Demonstrator is to showcase the potential of this codesign approach applied to an all-European open hardware and software platform
- Focus on AI applications on Space for wildfire detection and satellite health monitoring
- Development ongoing, currently at end of Year 2 of the project

Stay tuned for more!

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www.isolde-project.eu

Contact: info@isolde-project.eu

www.linkedin.com/company/isolde-project/

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