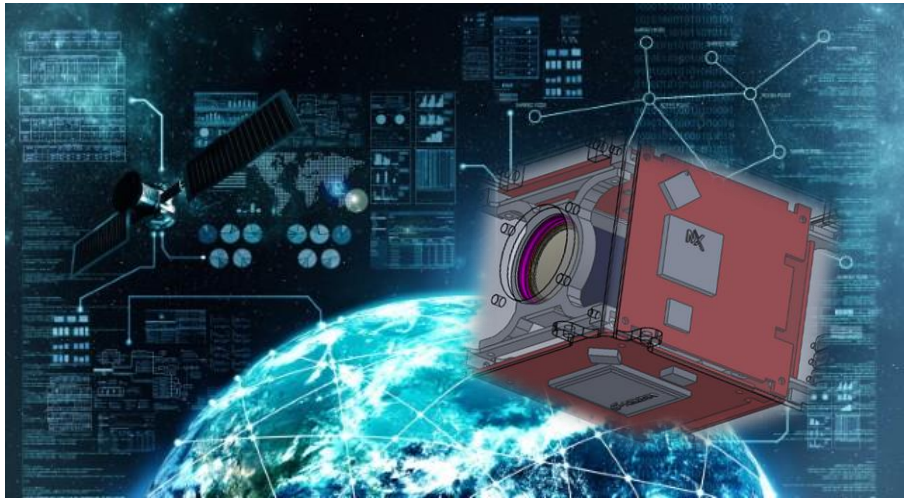
Deep Learning acceleration using MBD workflow in secure in-flight HW/SW reprogrammable SoC

SEFUW'23, ESTEC (The Netherlands)- dgarjona@gmv.com



D. Gonzalez-Arjona
J. Ferre
A. Perez
A. Jiménez-Peralo

esa cnes
5th SEFUW
SpacE FPGA Users Workshop
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gmv INNOVATING SOLUTIONS

Space-Based Surveillance System

Context

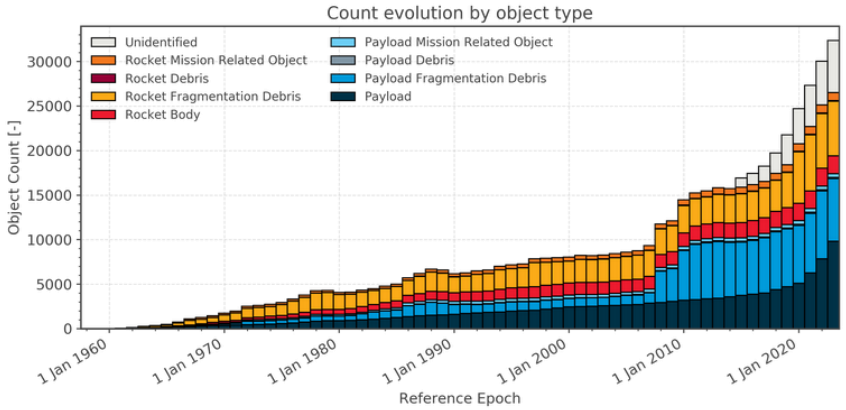
1. **Assessment of in-orbit satellite servicing for monitoring and tracking debris/objects in MEO/LEO**

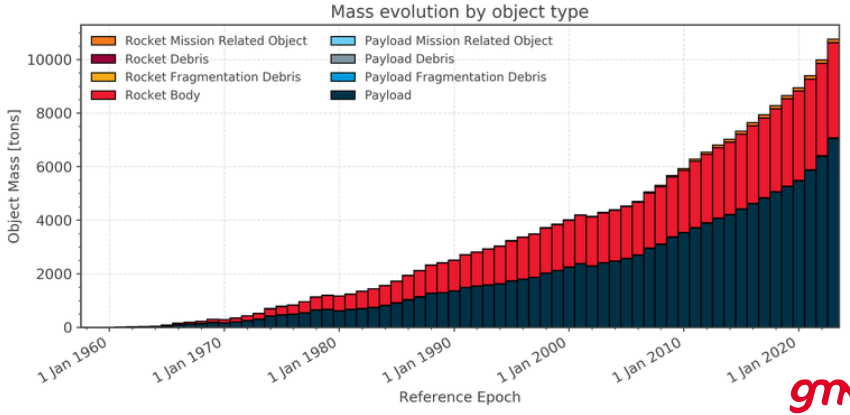
2. **Experimental Payloads** On board Galileo G2 satellites as secondary **service** (stand-alone)

3. **Edge Computing:**
   In-Orbit FPGA High Perf Real-Time
   Computer-Vision acceleration → AI CNNs**?**

4. **Cost-Effective** solution that complements ground-based tracking and deduces data downlink. Space Situational Awareness (SSA)

5. Absence of atmosphere. Good timeliness.
   Not weather-based degradation.
   Reduction of ground-sat communication



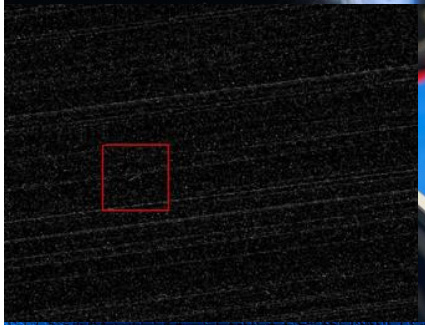


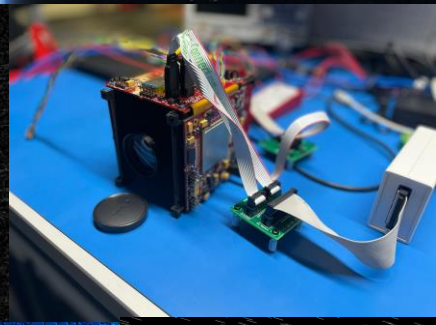
SBSS payload subsystem

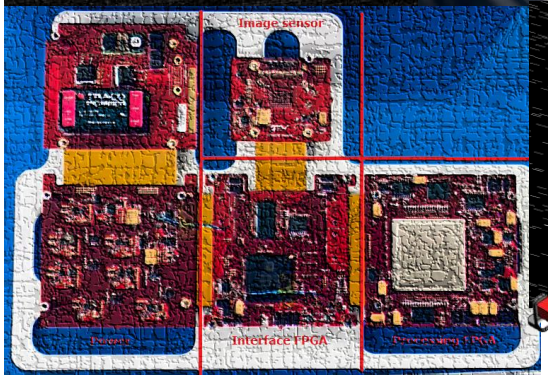
- Prototype avionics "Elegant" **BreadBoard**
- **100%** in-house (concept, algos, micro, electron, mechanic)
  - ❑ Imaging **sensor** and **Computing** Electronics
  - ❑ On-Board **Algorithms** detecting light curves and discriminating artificial objects from known stars
  - ❑ Avionics **Architecture** (Camera + Co-processor, 1 **single-unit**)
  - ❑ FPGA and PCB Design (**rad-hard** representative)
- Concept **Trade-off** analysis, Demonstration and Experiment
- LEO/**MEO Detection** and Tracking of **Debris**
- **Autonomy** and On-board HW/SW
- **High-performance** computer-vision algorithms
- in-flight reconfiguration to use the camera in combination with a **different vision-based purpose**

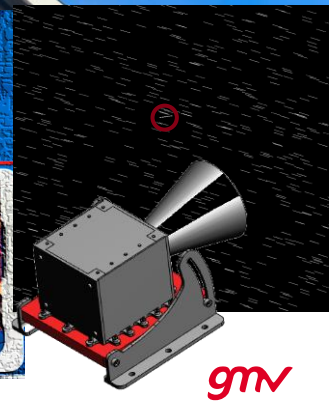
¿ Can we Benefit from an on-Board Deep Learning Solution?

¿ Can we follow an Agile process to evaluate suitability?









NN state-of-the-art

Most of the solution are ground-based

Wide research been developed for on-ground applications.

Motion of the stars is well-known and a precise pointing control can be performed to keep the stars background still with respect to the camera image.

Only moving object in the image is the debris/object and a neural network can be easily trained to perform debris detection

Classification techniques to discriminate between static and moving objects in the image.
Create stars masks to perform image masking and, therefore, to detect possible debris in the image.

Detection and classification need still starry background. This constraint limits the maximum possible exposure time, directly affecting the maximum observable visual magnitude of the debris.

Model-Based Design → High-Level Synthesis

Nngen, Taste and complementary scripts

Fast End2End Prototyping based on open-source

From algorithms to Board Execution

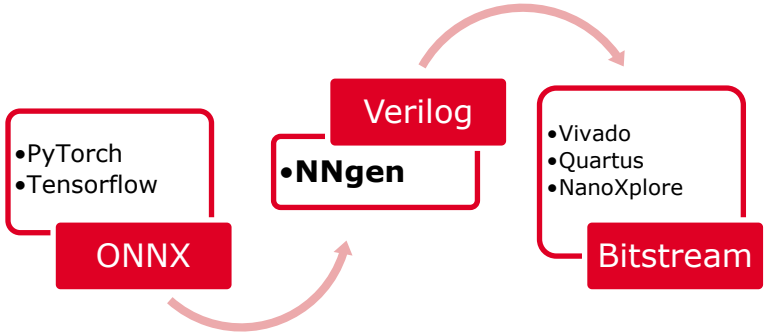
NNGen customizable HW synthesis for DL:
- Konica Minolta & Shinya Takameda-Yamazaki (Univ Tokyo)

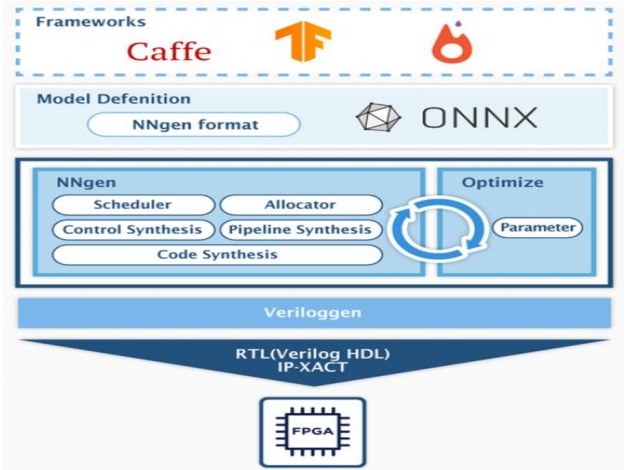
Data Types Selection and Quantization for:
- Inputs (mean, std), Bias, Weights

10x speedup Performance vs SW
- VGG-11 & ResNet on ImageNet
- Digit classification

Verilog HDL source and IP-XACT IP-core pacakge

Veriloggen Backend open-source



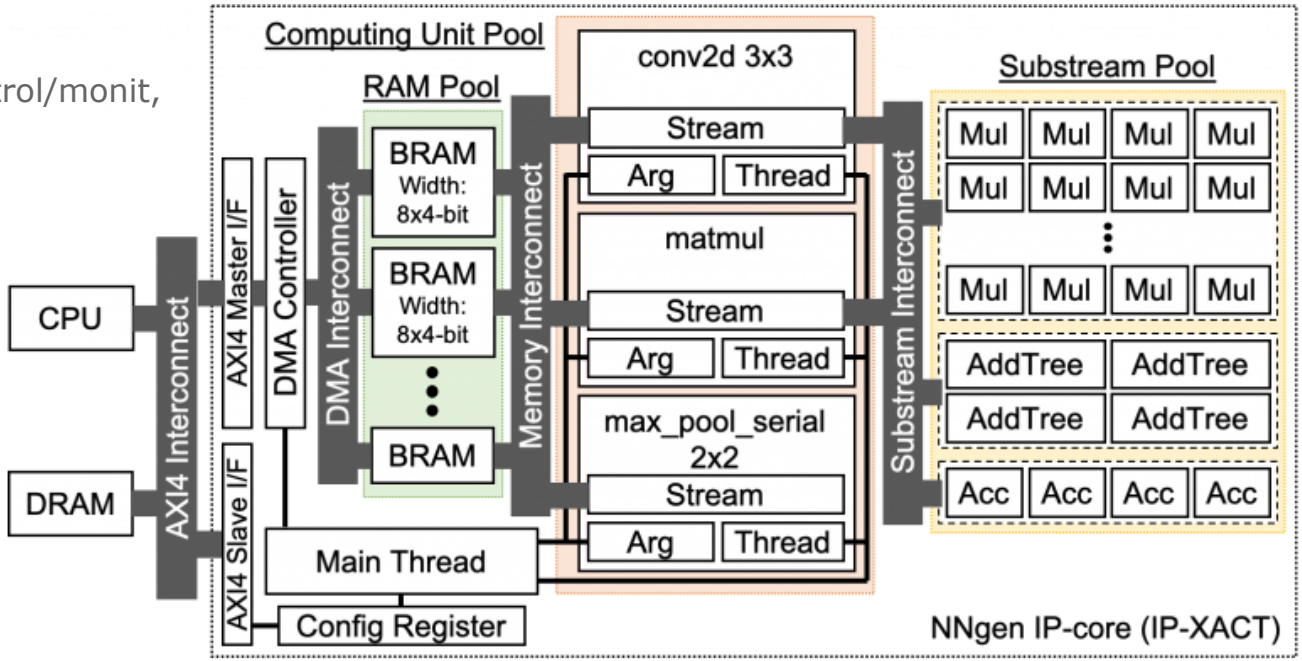


Nngen framework

FPGA deployment

What you get:

- DL IP Verilog,
- AXI-full burst transmission,
- AXI-lite register set for control/monit,
- external memory map,
- internal buffers



Source: https://research.konicaminolta.com/en/technology/tech_details/nngen/

Paradigm Comparison

Still more options available

Deep Learning Accel:

a) HDL handwritten ad-hoc IP
   a) General DL IP
b) SW-based HLS Flow
c) Other MBD options
   a) Mathworks ;)
   b) SODA-OPT (+Bambu HLS)
   c) Xilinx DNNDK
   d) Xilinx FINN (QNN)

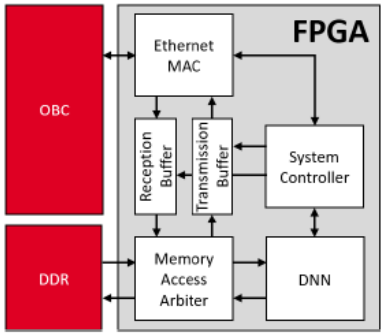


Figure 4: Avionics diagram

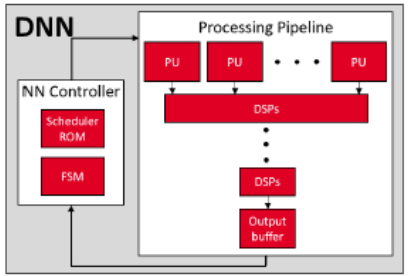


Figure 5: Block diagram of the DNN

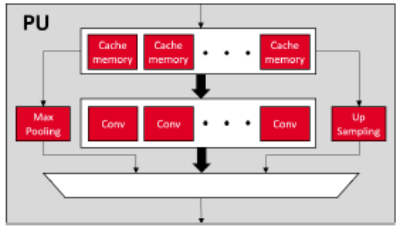
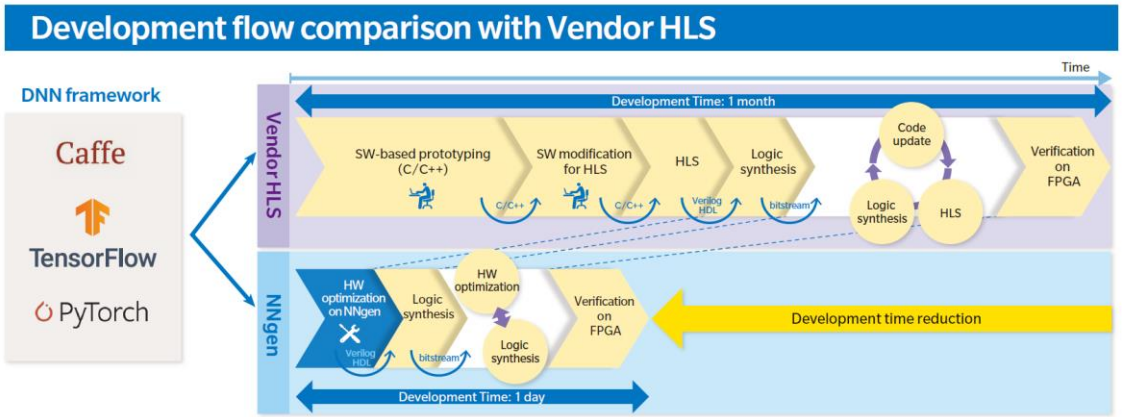


Figure 6: Block diagram of the Processing Unit

Figure 4, 5 and 6 shows architecture of hand-written HDL-coded GMV's Deep Learning FPGA accelerator



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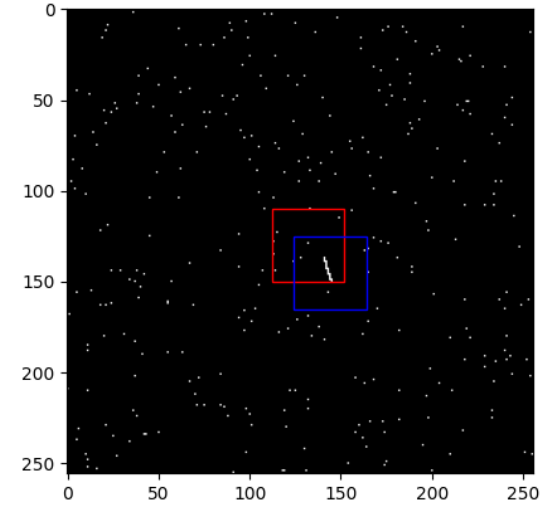
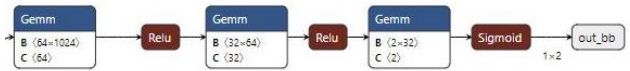
Why updates for machine learning?

Architecture choices: Localization head depth

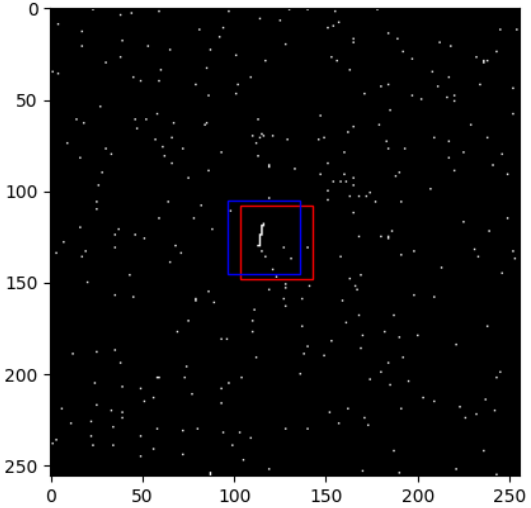
Avg. IOU = 0,28

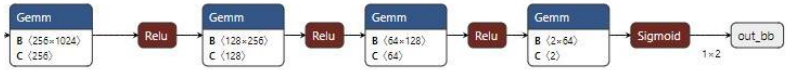




Significant IOU improvement

Avg. IOU = 0,74

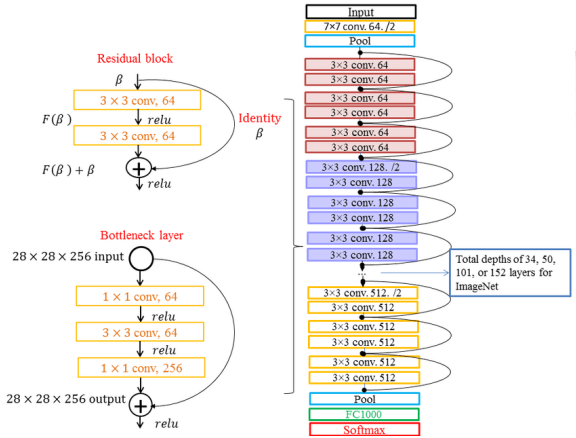




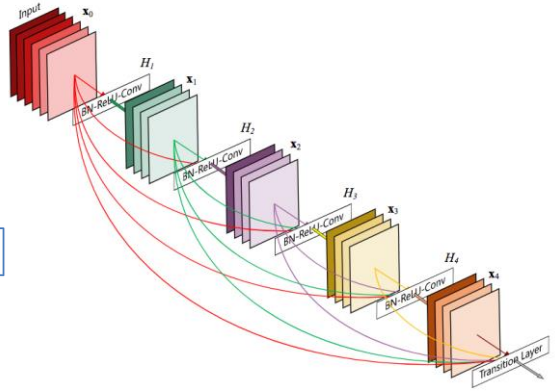
Implemented architectures

Feature extraction: Residual network backbones

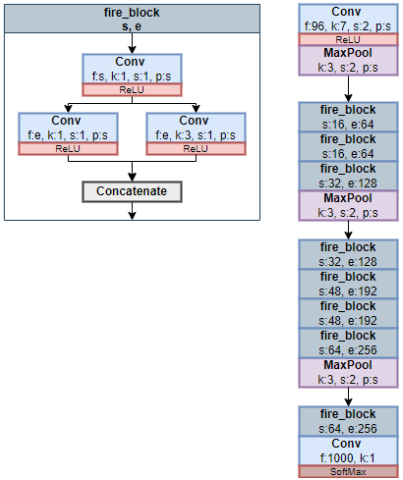
ResNet



DenseNet

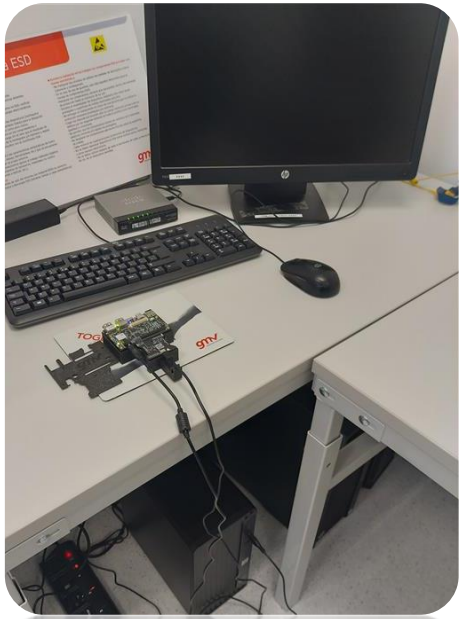


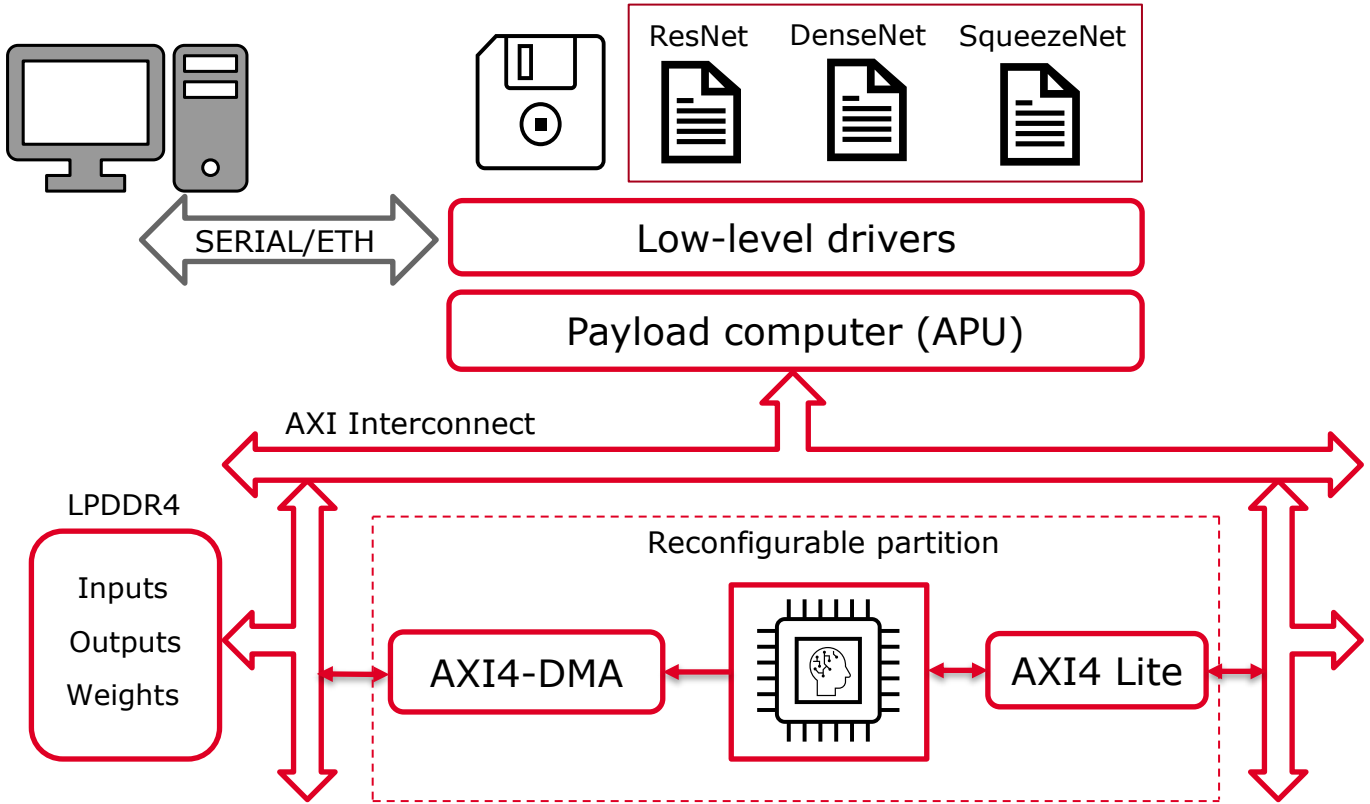
SqueezeNet



Reconfigurable platform

Test setup

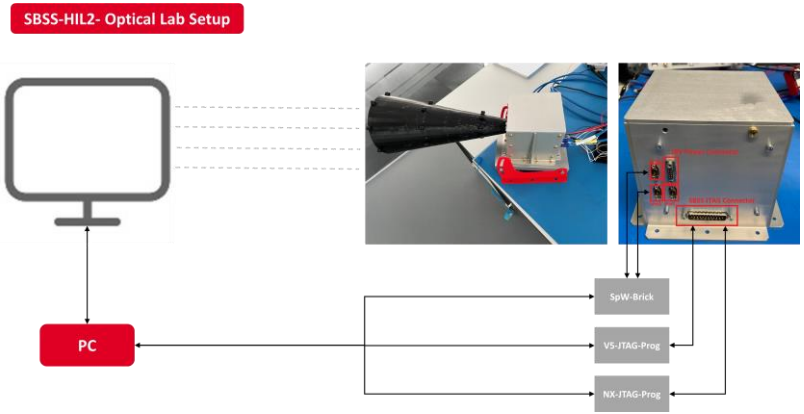


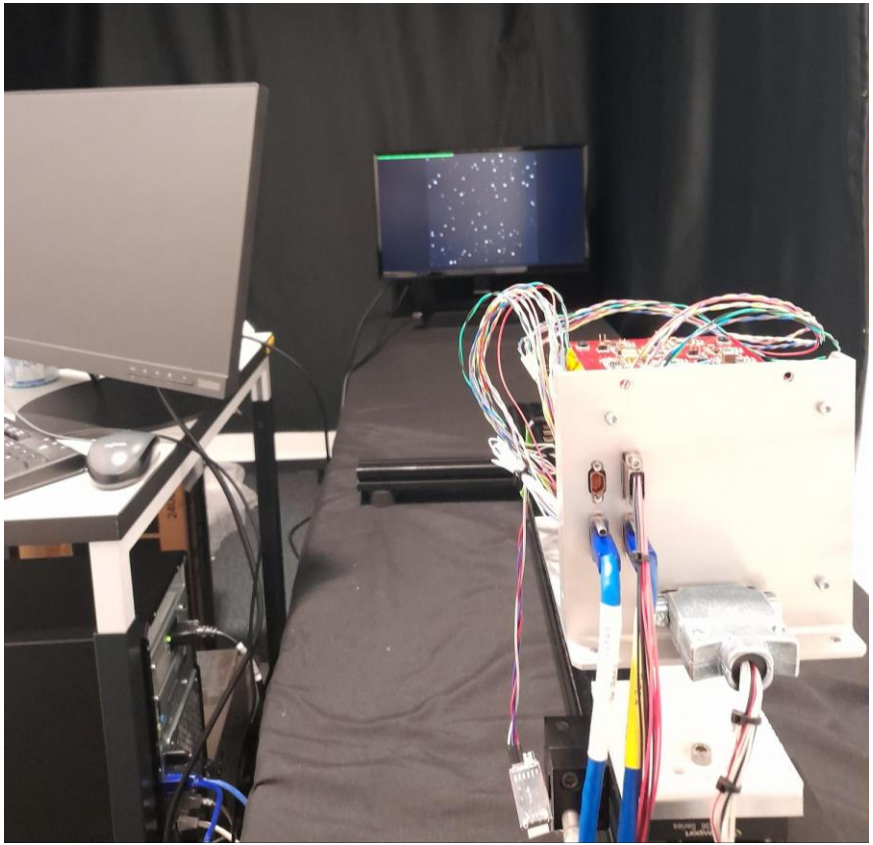


HW-In-the-loop Dataset– SBSS HW Prototype

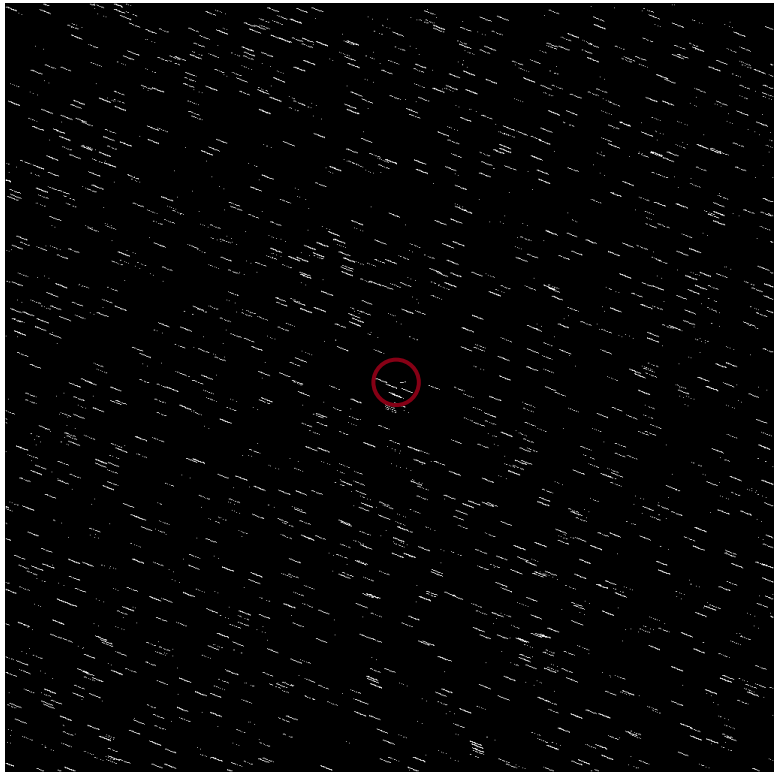
- Optical Laboratory HW-in-the-loop using G-Theia1 camera
- Representative conditions, actual HW
- HW Dataflow Embedded Camera
- HW Dataflow External Camera
- End to End Test Cases
- System Test Validation & Verification

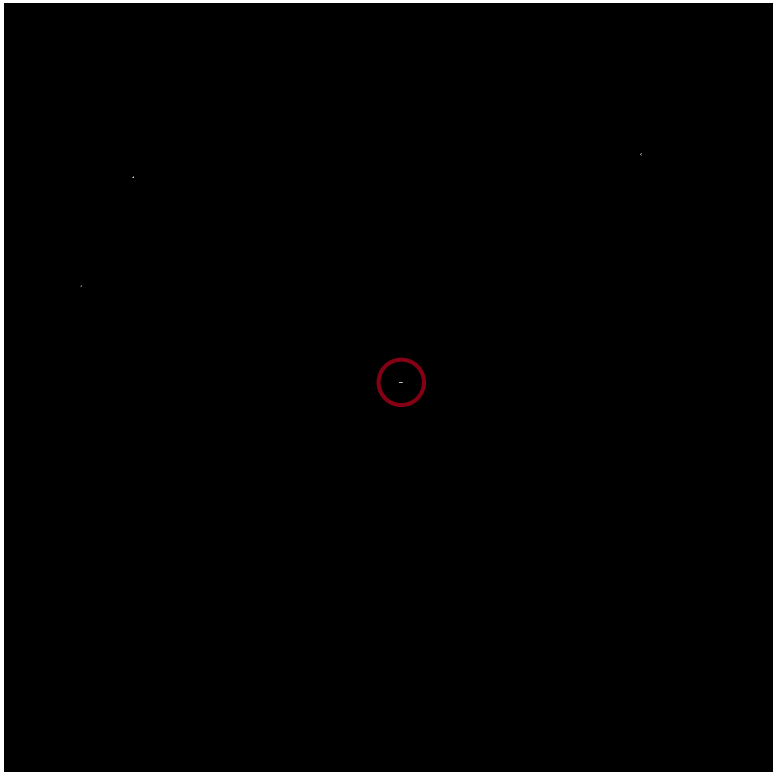
Setup



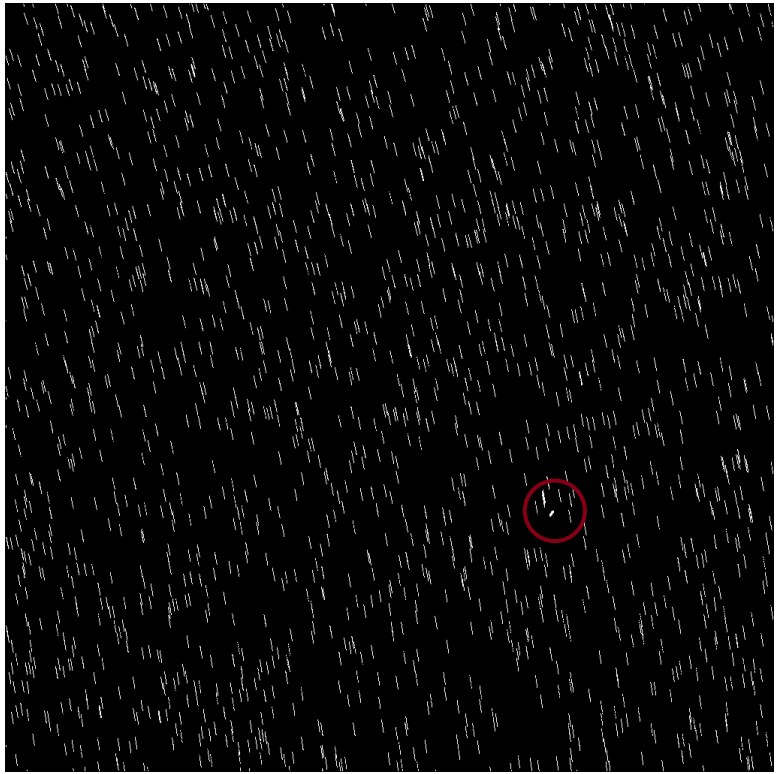


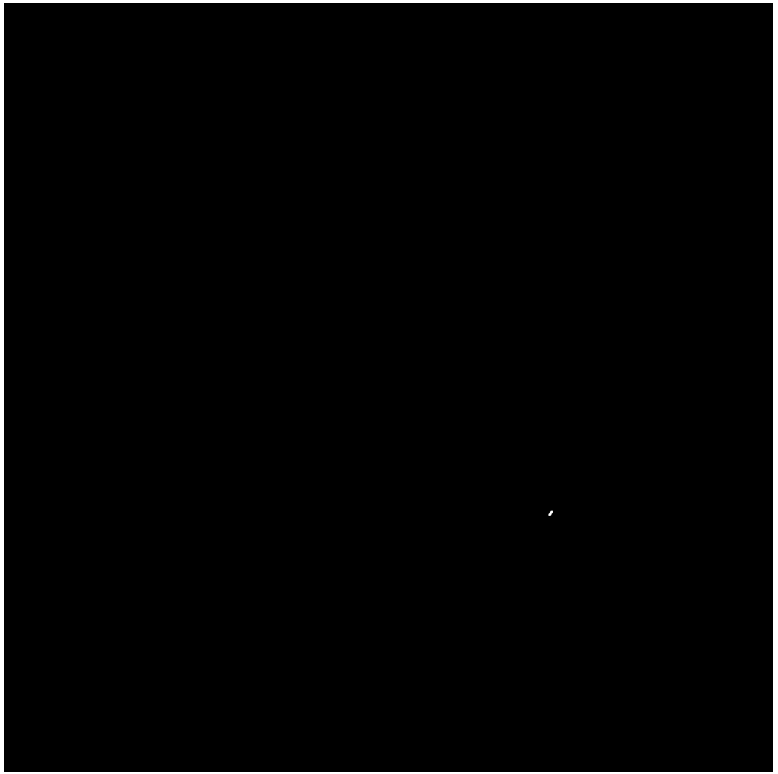
Visual examples (1/2)





Visual examples (2/2)

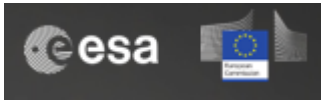




Thank you

Authors list:

- **GMV Aerospace and Defence SAU (Spain):**
  - **D. Gonzalez-Arjona**
  - **J. Ferre**
  - **A. Pérez**
  - **A. Jiménez-Peralo**



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Acknolewdges to the GNSS Evolution Team and ESA Technical Officers

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