AGENIUM SPACE

OPS-SAT Experimentation
DeepCube Service IOD/IOV
Final Review

ESA-AGENIUM Space

08/12/2022

Objective

Semantic segmentation of forests using **binary neural networks** implemented on the **Cyclone V SoC** on board the **OPS-SAT** satellite

Summary

1/ Context – DeepCube service

2/ Hardware Implementation

Embedded Solution

Design Overview

Execution Flow

3/ Data processing

Parallel with Sentinel 2 images (Copernicus data)

“on boarding ready” AI model

3/ Final Package

Execution Flow

Experimenter Experience / Feedback

Results on Ground

Results On-board

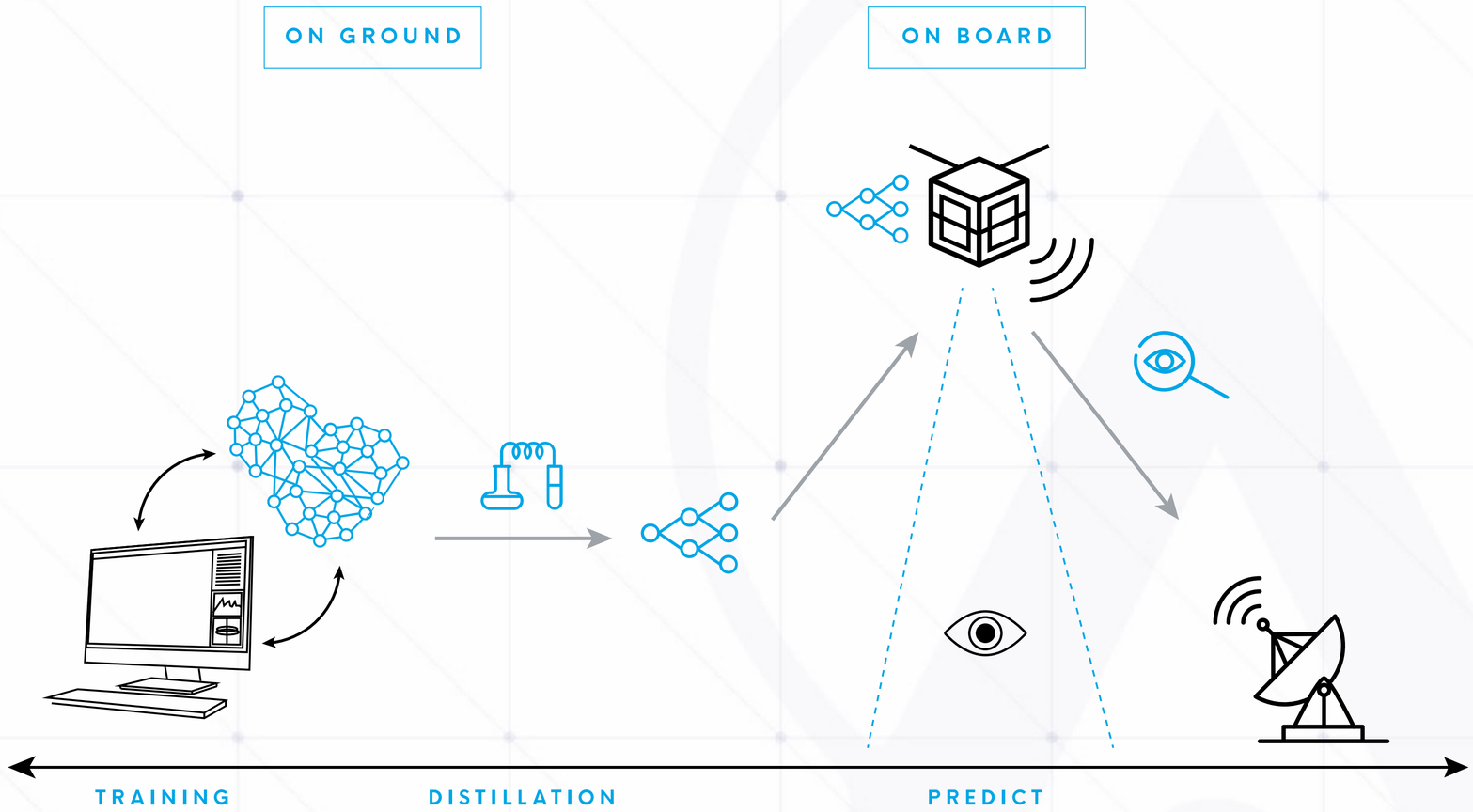
DeepCube service:
bring your AI on-board

Based on an end-to-end process: from a state-of-the-art DNN to on-board deployment

A generic methodology: simplify any classification, segmentation or detection DNN

A minimal loss of accuracy

With special care for space constraint: throughput, power consumption



AI at the edge : DeepCube service IOD/IOV - OPS-SAT Campaign

- Goal of the experiments is to execute on board inference of the simplified models implemented in previous projects (DeepCube, CORTEX)

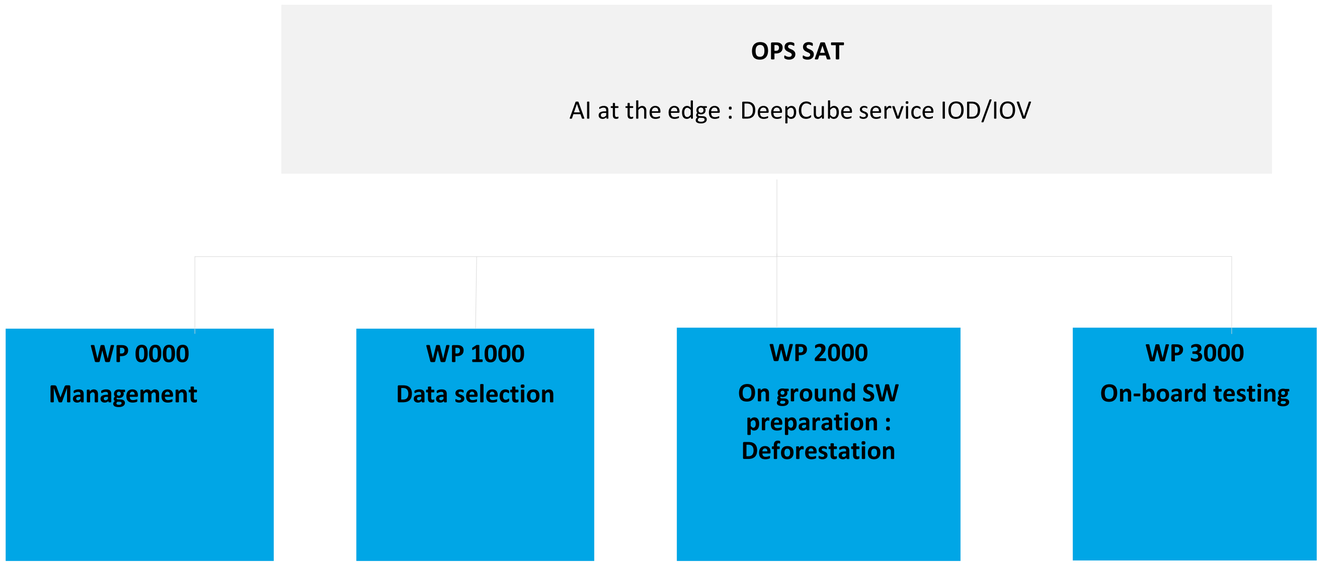
- Chosen experiment is Deforestation:

Very powerful experiment as it deals with several different technical aspects such as pixels wise inference of segmentation on-board, management of errors in geometric data superposition and coping with reference data storage and handling

- The inference SW has been ported and validated in several hardware devices used in space missions : Xilinx Ultrascale, AMD G-series

DeepCube service IOD/IOV

WBS



DeepCube service IOD/IOV
Use case

- It has finally been too complex in the project's time frame to achieve the deforestation use case (ie change detection) initially planned:
  - Implementation on the Cyclone V has been a challenging task
  - Interfacing with OPS SAT EM took us a longer time than expected
  - In the end we do not have any ground truth on the area where the images will be acquired (Tropical forest of South America)
  - Geolocalization incertitude of the raw images
- The use case implemented is finally **forest detection (segmentation)**
- **We will peform on ground change detection on the inputs & outputs of the in-flight experiment run to demonstrate initial approach validity**

2/ Hardware Implementation

- Embedded solutions
- Design Overview
- Execution Flow

2/ Hardware Implementation
Embedded solutions

High Level Synthesis

Generation of VHDL with high level code (often OpenCL)
Based on HLS manufacturer's tools
Supports various precisions (inference)

FINN

hls4ml

PipeCNN

...

Intel's OpenVINO tool

General-purpose tools to run AI on intel's FPGA, VPU, CPU, GPU

Seems to support only Arria 10 FPGA
→ Adaptable?

Supports only **INT8** and **FP** inference

OpenVINO™

Agenium Space Custom solution

VHDL module (Convolutions, Activation, …) + automated model transcoding with Python

→ **Binary Models only** (avoids a lot of problems)

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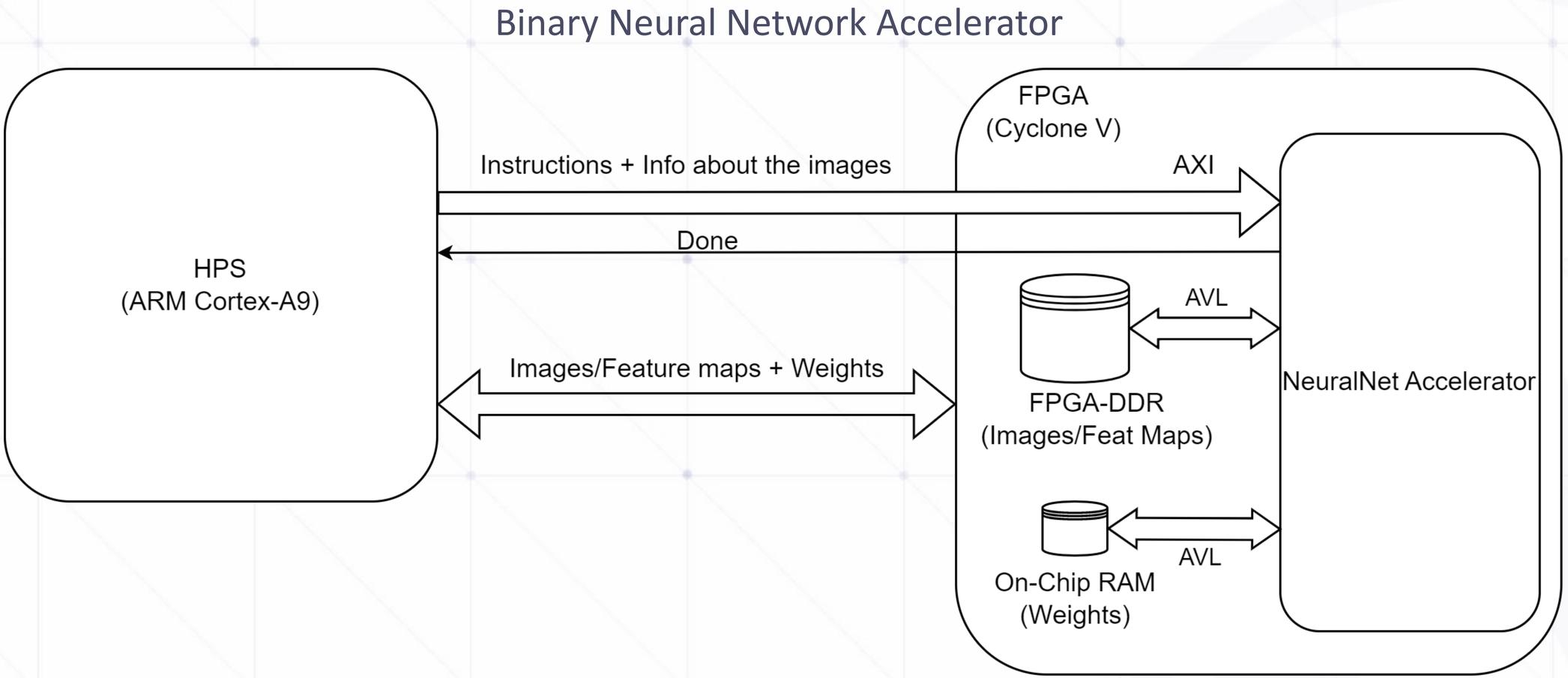
2/ Hardware Implementation

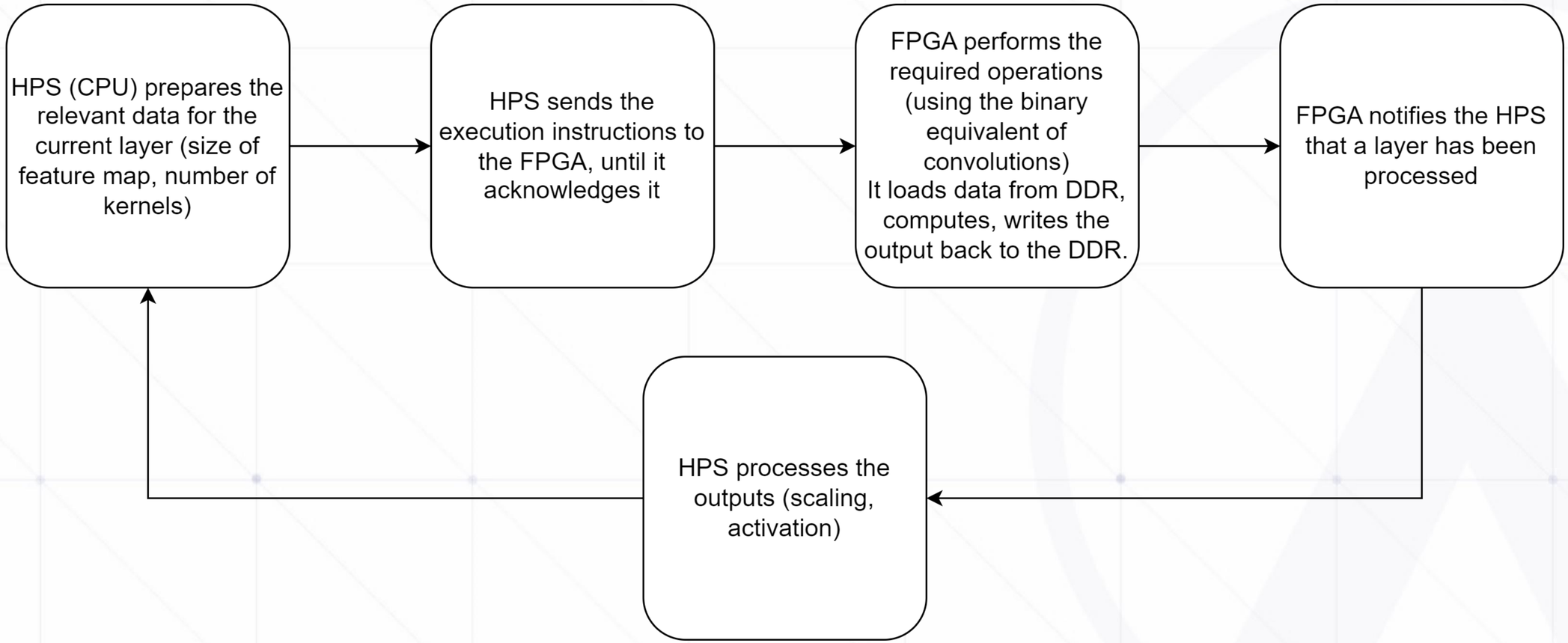
Design overview



Block diagram of the accelerator and the connected memory devices

2/ Hardware Implementation

Execution flow



Sequence of operations during inference

Multiple layers need to be processed per image. The HPS is in charge of the proper ordering of layer operations in the FPGA.

2/ Hardware Implementation

Experiment constraints

- Limitations due to the hardware used (Amount of logic resources and on-chip memory available)
- Software should not have a peak memory usage greater than ~300 MB
- FPGA Modules should not take up more than 64 MB
- Hardware project should be synthesised with Quartus 17.0.

3/ Data processing

- Parallel with Sentinel 2 images (Copernicus data)
- “on boarding ready” AI model

3/ Data processing

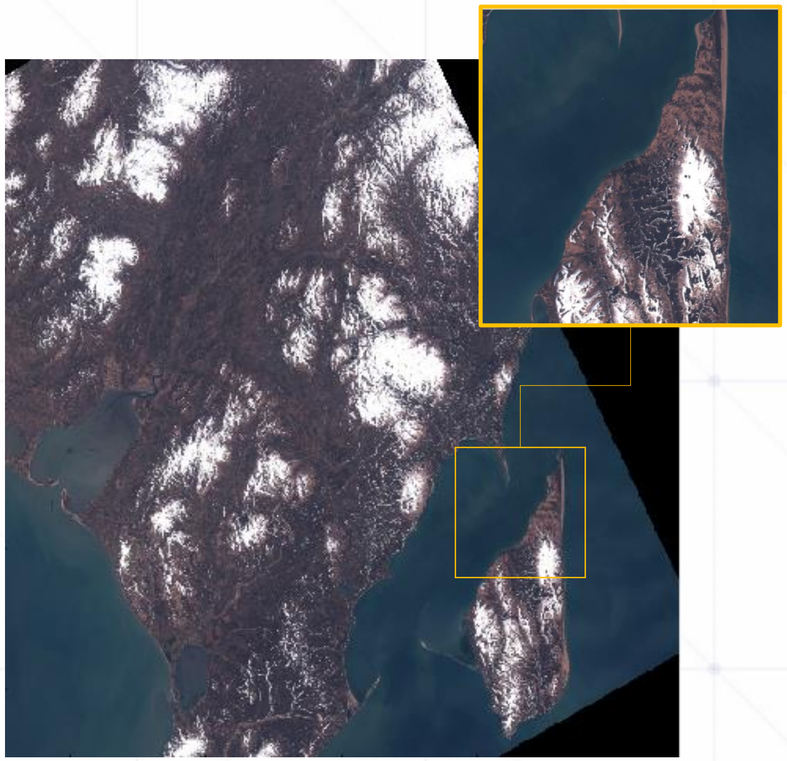
Parallel with Sentinel 2 images (Copernicus data)

Sentinel 2 :

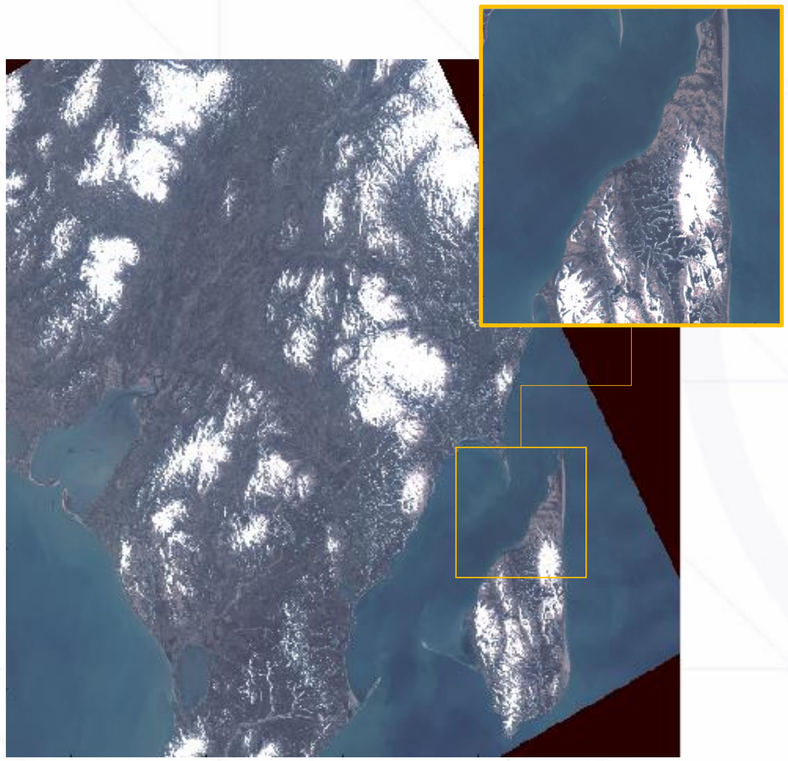
important amount of data

Small tiles over whole France with associated forest masks.

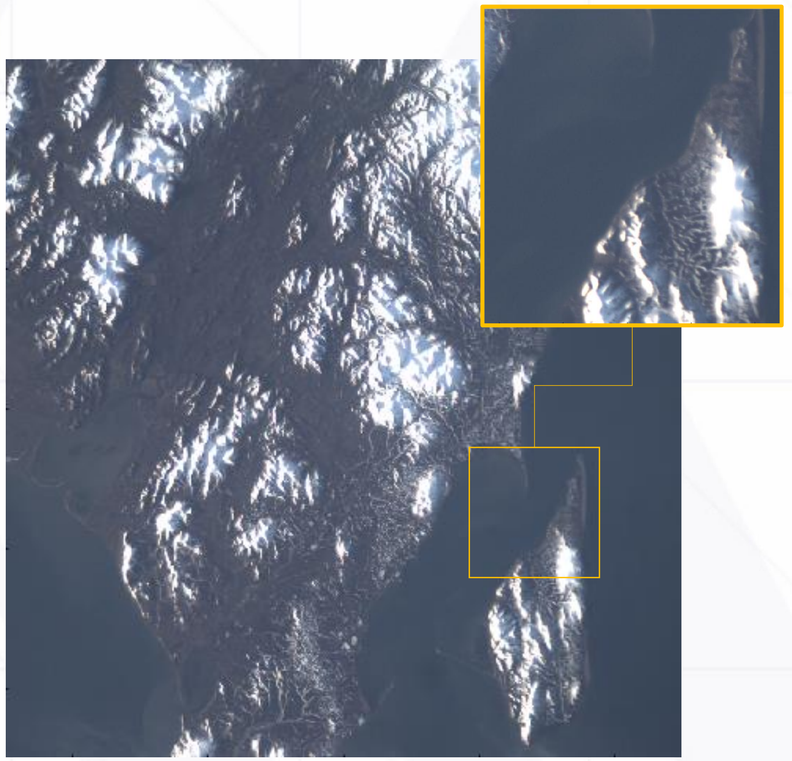
Possible to pre-process the database so that the images look like OPS-SAT images.



S2 image taken over Alaska



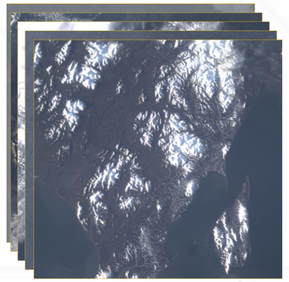
OPS-SAT-like S2 image

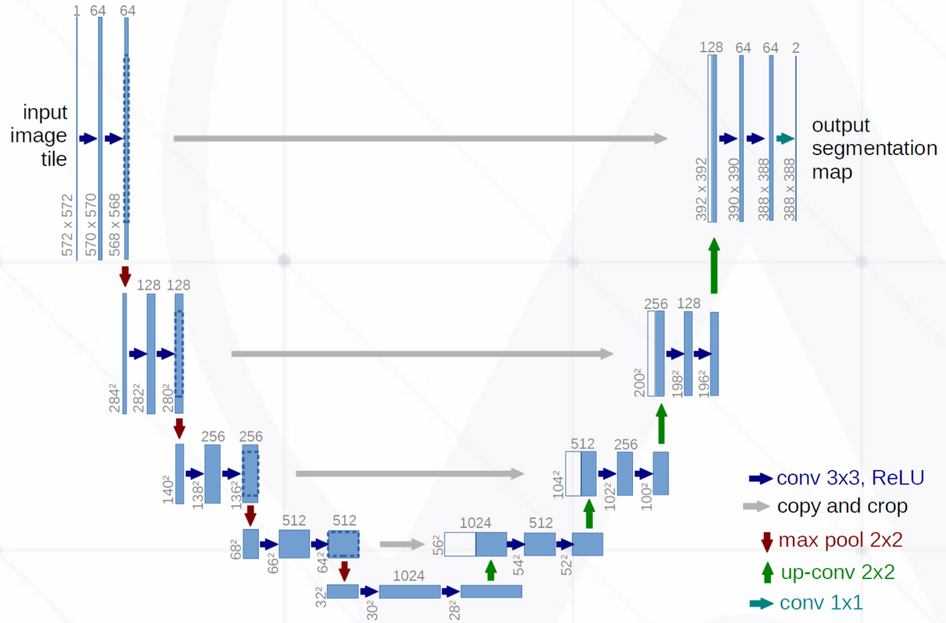


OPS-SAT image taken over Alaska 2 days before

3/ Data processing
“on boarding ready” AI model

- 600 « S2 » tiles over France
  OPS-SAT simulated images
  high quality ground truth
- 30 OPS-SAT images
  debayerized
  labeled
- Segmentation binary neural network
  background
  forest
  clouds
- Process 25x25km² at a single time



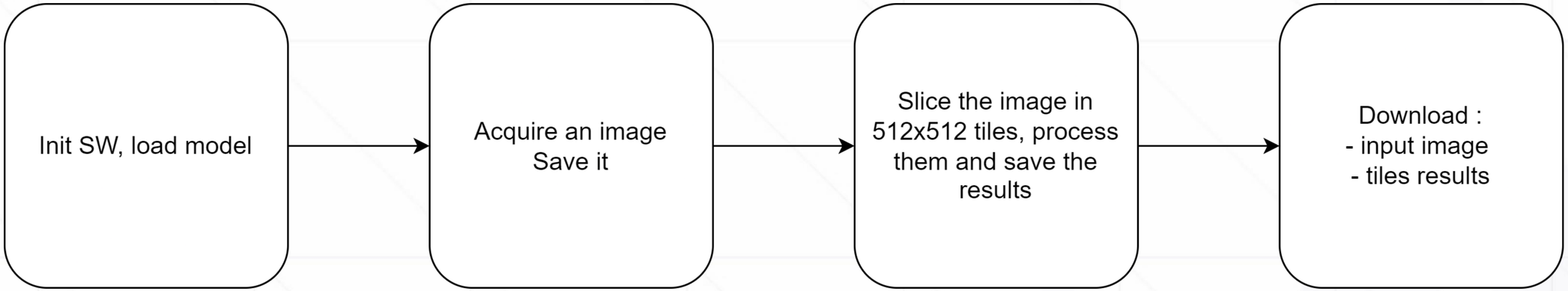


Classical UNET architecture for segmentation

4/ Final Package

- Execution Flow
- Experimenter Experience / Feedback
- Results On-board

4/ Final Package
Execution Flow



Sequence of operations during inference

4/ Final Package

Experimenter Experience / Feedback

- Issues / Difficulties:
  - SEPP DDR memory interface
  - Camera API not up-to-date
  - Quartus/QSYS compatibility issues (WSL, Linux+17.0)

- Pros:
  - Quick responses from OPS-SAT Team
  - Explanations very clear
  - FPGA Project example
  - OPS-SAT wiki

4/ Final Package

Results on-board (To be completed once results are available)

Conclusion

Experiment goals for Agenium Space

- ✓ Validate early versions of our custom binary neural network inference accelerator
- ✓ Proof of execution on "new" hardware and relevant tools (Intel FPGA)
- ❑ Perform on-board segmentation

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