Seminário da CAP

Review on Architectures in the Space Domain to support AI and DevOps: Midterm Findings & GSSI opportunities

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GRAN SASSO
SCIENCE INSTITUTE

Outline

- Introducing myself
- Space Architectures
  - Project context
  - Research Method
  - Preliminary Results
- GSSI opportunities
  - PhD program
  - Postdoc

Background

- Bachelor on Information Systems (Unesp).
- IT consultant.
- Mastering in Electronic and Computer Engineering (ITA).
- Doctorate in Applied Computing (CAP-INPE). Supervisors: Prof. Vijaykumar and Prof. Valdivino.

Current Position

- Professor at IFSP - Instituto Federal de Educação, Ciência e Tecnologia de São Paulo - Campus Jacareí (since 2014).
- Postdoctoral researcher at GSSI - Gran Sasso Science Institute (since 2022).

Review on Architectures in the Space Domain to support AI and DevOps

GSSI & Thales Alenia

Gran Sasso Tech

- Thales Alenia Space (joint venture between Thales 67% and Leonardo 33%).
- Agreement for the birth of the "Gran Sasso Tech" foundation which aims to stimulate research and innovation.
- Strengthening of the exchange between basic research that takes place in the university and applied and industrial research.
  - Space
  - Silicon technologies and
  - Software systems

THALES

LEONARDO

G S S I

Digital platforms for Space industry

https://www.thalesgroup.com/en/countries/europe/italy/space-italy.

Project involving the following institutions: GSSI, TAS (Thales Alenia Space), and FBK (Fondazione Bruno Kessler)

Onboard SW platform for New Space Applications

This task aims at developing innovative SW architectures, with SW relevant technologies, that go beyond the current concept of platform and payload disjoint processing, converging into a single SW platform for New Space Applications. The idea is to develop an In-orbit framework with DevSecOps technologies that allows the development, testing and deployment of FLIGHT SW even when the SW platform is in orbit. The framework engines will be designed to host accelerators for artificial intelligence, capable a very high level of autonomy on board, integrating the most modern AI libraries developed on the new space market (as a reference Tensor Flow, Klepsydra, etc). This technology will allow AI maneuvers, AI reconfigurations and on-board diagnostics-based AI, with a virtual AI operator that will limit the management costs of complex software from the ground stations.

Objective

Main goal: surveying the state of the art in software, hardware, and electrical architectures in the space domain able to support Artificial Intelligence (AI) and/or promote DevSecOps.

Research Method

Research questions and their rationales

Nº	Research Question	Rationale
RQ1	Trends and statistics: when and where the studies have been published?	The objective is to understand whether there are specific publication sources for these studies, and when they have been published.
RQ2	Which architectures have been identified to support AI and/or promote DevSecOps in the space domain?	The idea is to see if the architectures allow AI and/or the development, testing, and deployment of software in orbit. We want to see if it is possible to categorize them.
RQ3	How these architectures have been evaluated?	The interest is to know how they conducted the experiments, if they use simulation, real case studies, etc, and if there is a comparison with other techniques/tools.
RQ4	What are the main challenges to face when dealing with space domain restrictions?	Highlights relating to the main difficulties when dealing with technologies for space domain. This is useful for researchers and practitioners that intend to accomplish new initiatives in this field.

B. A. Kitchenham and S. Charters, "*Guidelines for performing systematic literature reviews in software engineering*," Technical Report, 2007.

Research Method

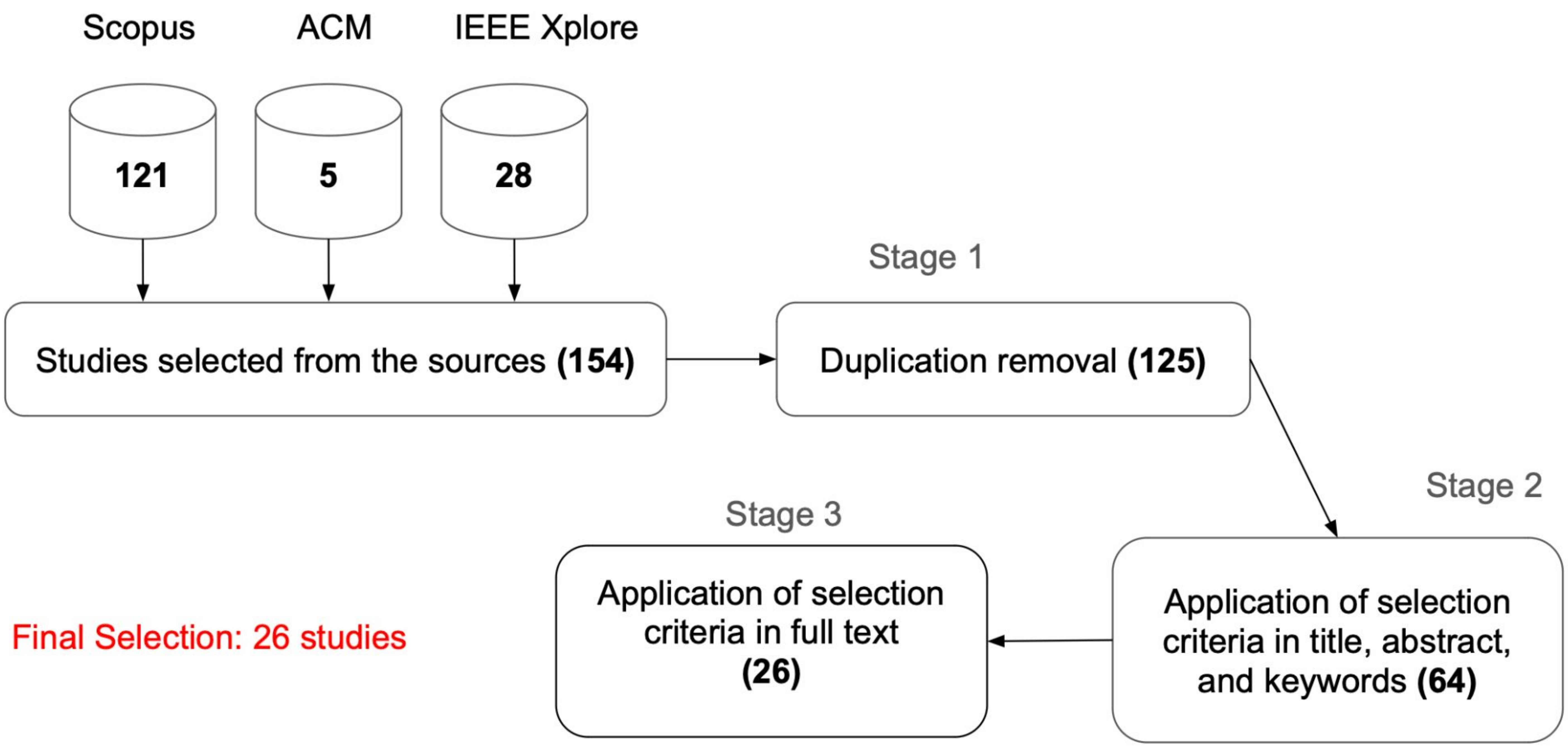
Search string: Areas & keywords

Areas	Keywords
Space	"space domain" OR "space context" OR "space environment" OR "space application*" OR "space system*" OR "space industry" OR "space area" OR "application space"
Architecture	"architecture" OR "framework" OR "platform"
SW/HW	"software" OR "hardware" OR "electrical"
AI/DevOps	"ml" OR "machine learning" OR "ai" OR "artificial intelligence" OR "intelligent" OR "smart" OR "devsecops" OR "devops" OR "continuous integration deployment" OR "CI/CD"
Search String: ("space domain" OR "space context" OR "space environment" OR "space application*" OR "space system*" OR "space industry" OR "space area" OR "application space") AND (architecture OR framework OR platform) AND (software OR hardware OR electrical) AND (ml OR "machine learning" OR ai OR "artificial Intelligence" OR intelligent OR smart OR devsecops OR devops OR "continuous integration deployment" OR "CI/CD")	

Inclusion and Exclusion criteria

- ICs - Study must be related to continuous development or AI, ML on board on satellites.
- ECs - Study mentions space domain, but it is applied to remote regions that do not belong to space domain, like deep ocean or ice. Also, space robots or rover are disregarded.

Search and selection SLR process



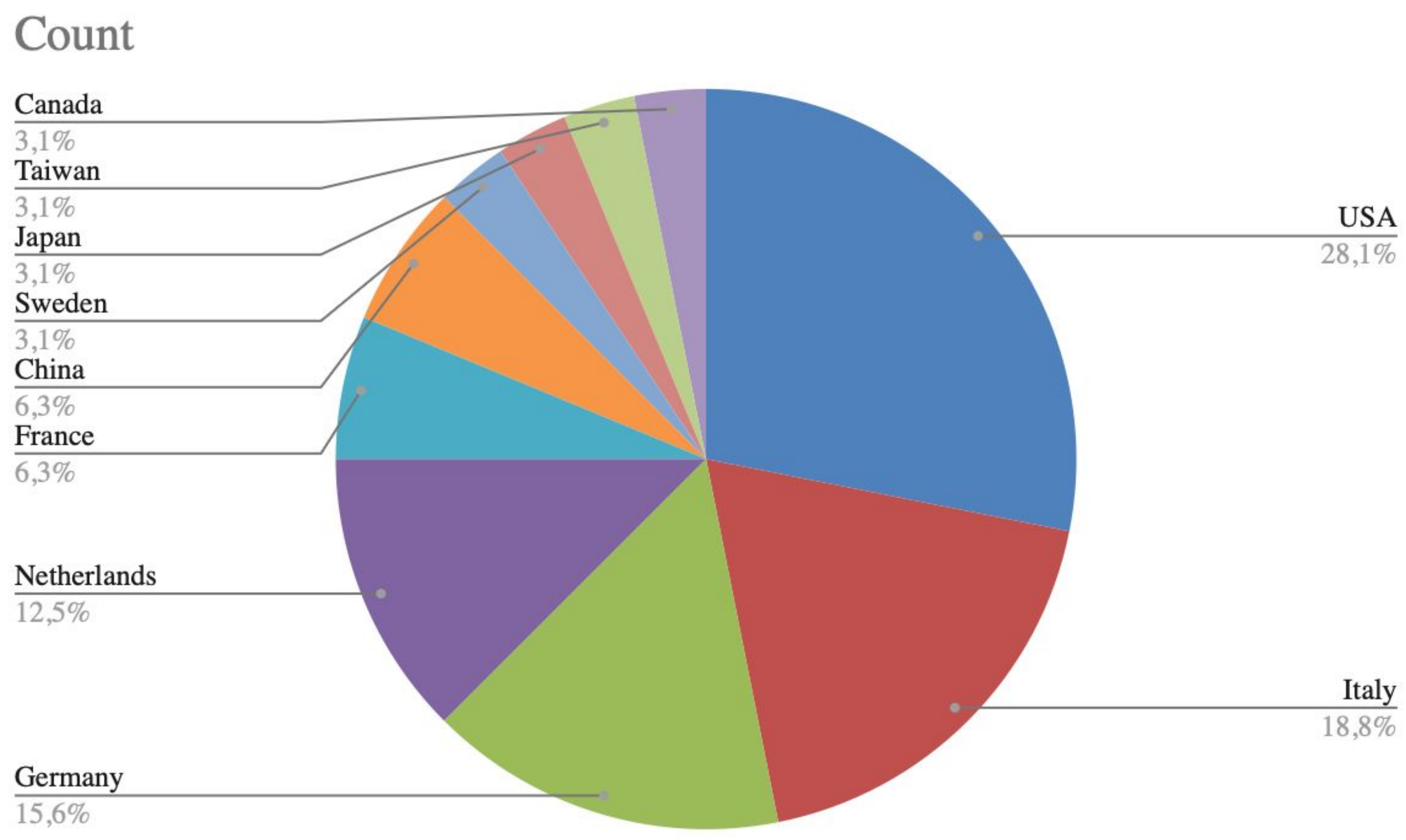
RQ1: Trends and statistics

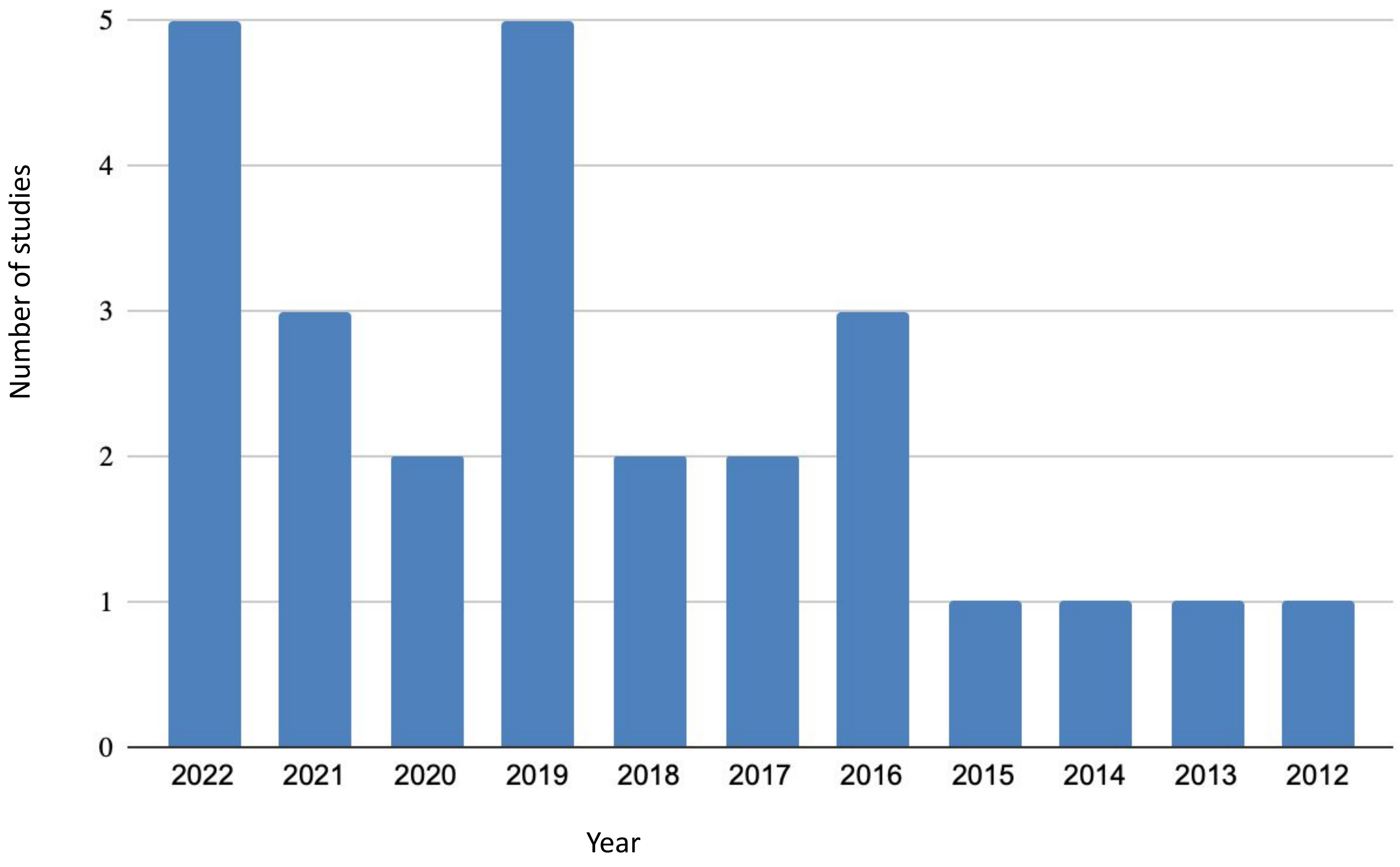
Publication venue	Acronym	#Studies
IEEE Aerospace Conference	AERO	8
International Astronautical Congress	IAC	6
IEEE/SICE International Symposium on System Integration	SII	1
AIAA Science and Technology Forum and Exposition	AIAA SciTech Forum	1
IEEE International Symposium on Defect and Fault Tolerance in VLSI and Nanotechnology Systems	DFT	1
IEEE High Performance Extreme Computing Conference	HPEC	1
IEEE Space Computing Conference	SCC	1
International Conference on Applications in Electronics Pervading Industry, Environment and Society	APPLEPIES	1
International SpaceWire Conference	SpaceWire	1
International Symposium on Computational Intelligence and Design	ISCID	1
International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications	CIVEMSA	1

Targeted publication venues

RQ1: Trends and statistics

When and where have the studies been published?





RQ2: How the architectures can be classified?

Categories of architecture contribution types

Category	Description
Emerging architectures for AI & CI/CD	Studies that are capable of offering architectures that can promote either AI and/or CI/CD.
AI applications	Initiatives showing the use of AI techniques in several types of application, ranging from prediction, efficiency to image recognition.
High processing and autonomous capabilities	Shows initiatives to promote high-performance processing to promote autonomous space systems by providing high-level decision making, robust execution of decisions, and automatic fault repairing.
High speed and intelligent space networks	Brings works handling high-speed space networks.
Infrastructure/Hardware	More related to works on infrastructure and hardware for the space domain.
Overview, guidelines, highlights	Studies that do not present concrete results, but overviews and interesting highlights for the space domain.

RQ2: How the architectures can be classified?

Distribution of articles by category application

Category	Study
Emerging architectures for AI & CI/CD	A_1, A_5, A_{17}
AI applications	A_3, A_7, A_8, A_9, A_{10}, A_{11}, A_{14}
High processing and autonomous capabilities	A_{13}, A_{16}, A_{22}, A_{24}, A_{25}
High speed and intelligent space networks	A_{12}, A_{20}, A_{21}
Infrastructure/Hardware	A_{18}, A_{19}, A_{23}, A_{26}
Overview, guidelines, highlights	A_2, A_4, A_6, A_{15}

Technical Details

Snapshot of information relating to the technical features of the analysed architectures in the space domain

ID	Arch./ Method	Description	Processor used	HW accelerator	Commun.	Compat.
A_1	ICU4SAT	A programmable data handling and data processing System on a Chip (SoC) for modern ICUs onboard satellites.	64-bit RISC-V	FPGA-GPU (FGPU)	SpaceFibre SpaceWire	OpenCL, Tensor-Flow, PyTorch, and Caffe
A_5	OPS-SAT	It is a 3U CubeSat, the first nanosatellite to be directly owned and operated by the ESA.	ARM dual-core (Cortex-A9)	FPGA	S-band	TensorFlow--Lite Linux
A_{17}	SMART-PRO	A Space Multi-core Autonomous Real-Time Processor built with COTS components.	Quad-core Intel Xeon CPU E5-1620 v3	COTS GPU Quadro P500 by NVIDIA	-	-
A_7	1)Vitis AI 2)XLA HLS	Platforms to accelerate HW to deploy ML models.	Xilinx	FPGA XQRKU060	-	TensorFlow, Caffe, PyTorch, and Pentalinux

RQ3: How these architectures have been evaluated?

A13 - Aaron P Zucherman, John R Samson, and Benjamin K Malphrus. *High performance computing applications in space with DM technology*. IEEE Aerospace Conference, 2019.

It was launched to the ISS and the experiment was activated, running on-orbit checkouts, experiments, and capturing and compressing camera images.

Types of performed validation

Study	Real project	Experiment	Simulation	Case Study	Comparison
A1	✓				✓
A5		✓			
A7				✓	✓
A8		✓	✓		✓
A9				✓	✓
A10		✓			✓
A11		✓			✓
A12			✓		
A13	✓				
A16				✓	
A17		✓			✓
A20			✓		
A21			✓		✓
A23			✓		
A24		✓	✓		
A25		✓	✓		✓

GSSI

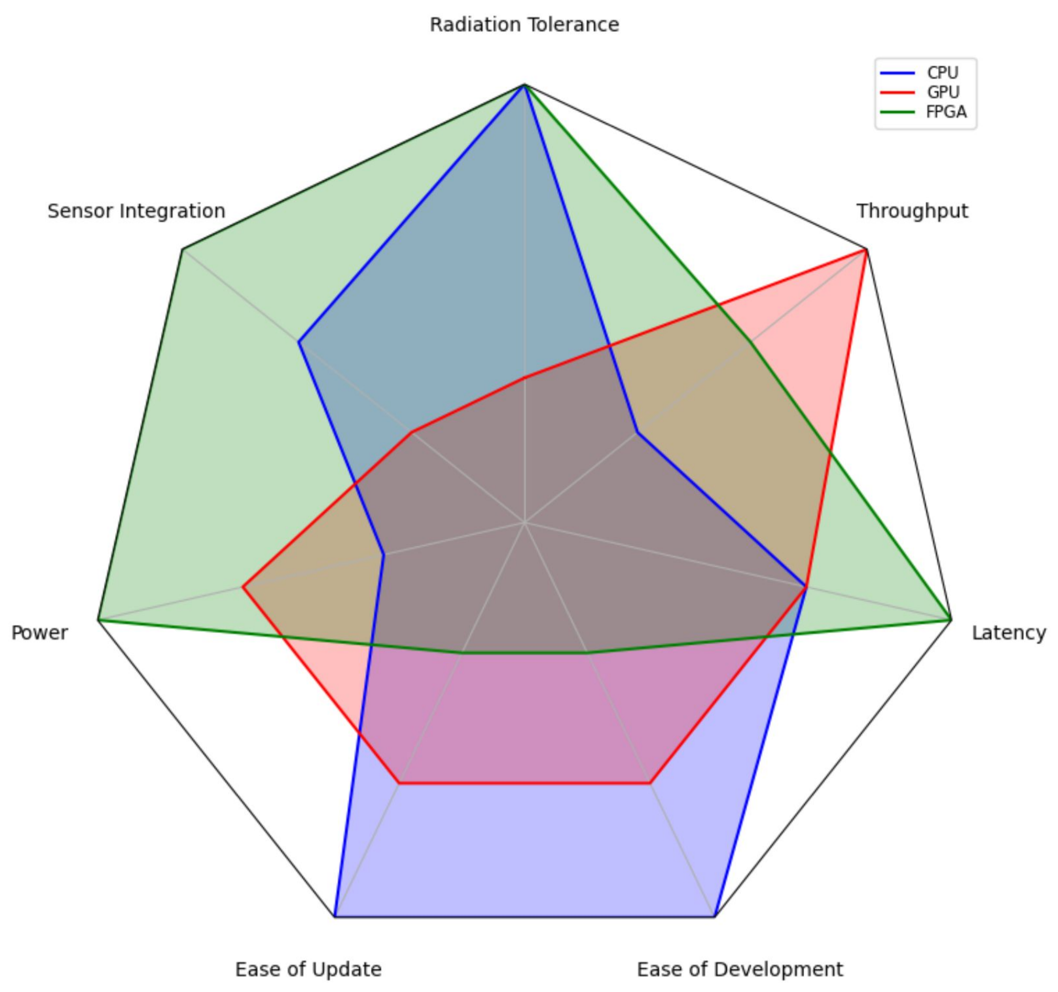
RQ4: What are the main challenges to face when dealing with space domain restrictions?

Topic	Challenge	Existing solutions
Environment	Wide temperature range, mechanical vibrations, vacuum and radiations.	
Hardware	Limitations on size, weight, and power (SWaP), processing and memory	Complex processing systems in the form of System on Chip (SoC) are becoming especially interesting. Commercial Off-The-Shelf (COTS) hardware accelerators to run on-the-edge applications are being developed. FPGA-based hybrid System-on-Chips (SoCs), which combine fixed-logic CPUs with reconfigurable-logic FPGAs, as well as GPUs, present numerous architectural advantages well-suited to address the computational capabilities required for high-performance, intelligent spacecraft.

RQ4: What are the main challenges to face when dealing with space domain restrictions?

Topic	Challenge	Existing Solution
Communication	Limitations both on bandwidth and on directionality with lower-frequency RF systems	Improvements in computational architecture have led to the development of superior waveforms while simultaneously offering remarkable new platforms and approaches to radio design (e.g., software- defined radio, or SDR). At the link level, SDRs are now being employed to continually poll and reconfigure link parameters to operate optimality. Alternative protocols for these situations have been developed and are in use (e.g., Licklider Transport Protocol). The more autonomous the satellites, the lower the cost of telecommunications and ground operations. The application of ML concepts for on-board processing can enable spacecraft to efficiently process immense volumes of raw sensor-data into actionable data to overcome limitations in downlink communication.
Culture	Risk-averse procurement behavior of the space industry leaves to long qualification process for space-grade components	

Hardware comparison



Subjects:

- Throughput: the quantity of data being processed through a system within a unit of time.
- Latency: the time taken from an input action to result in an output from the system.
- Sensor Integration: the process of retrieving data from a sensor, performing pre-processing steps and feeding the results into the model.
- Ease of Update: the difficulty in the process required to change the deployed model functionality.
- Radiation Tolerance: the tolerance of each piece of hardware to radiation exposure and commercial availability.
- Ease of development: the difficulty of deploying a model to each type of hardware.
- Power: the efficiency of computations with respect to power consumption for each type of hardware.

Veyette, M.J., Aylor, K., Stafford, D., Herrera, M., Jumani, S., Lineberry, C., Macklen, C., Maxwell, E., Stiles, R., Jenkins, M., Phase, D., "*AI/ML for Mission Processing Onboard Satellites*," AIAA SciTech Forum, 2022.

Discussions

- Deployment of a spatial device, such as a satellite, is becoming more and more accessible.
- Machine Learning is an attractive option for facilitating various tasks on space devices and reducing operating costs.
- Commercial-off-the-shelf (COTS) re-programmable devices, which are settled for all kinds of space missions can be the solution.
- The development of powerful processors as readily available commercial off-the-shelf OBCs or payloads is changing the landscape of the spacecraft computing environment and creating new opportunities for the space-segment to develop and deploy AI platforms.

GSSI opportunities

L’Aquila - Italy

GSSI

- International PhD school and a center for research and higher education.
- Created in 2016, as the Italian graduate school of advanced studies.
- A project supported by the Organization for Economic Cooperation and Development (OECD).
- The school welcomes professors, researchers and students selected internationally following the best graduate schools standards worldwide.
- Main goal is to strengthen the scientific excellence.

From https://www.gssi.it/institute/about

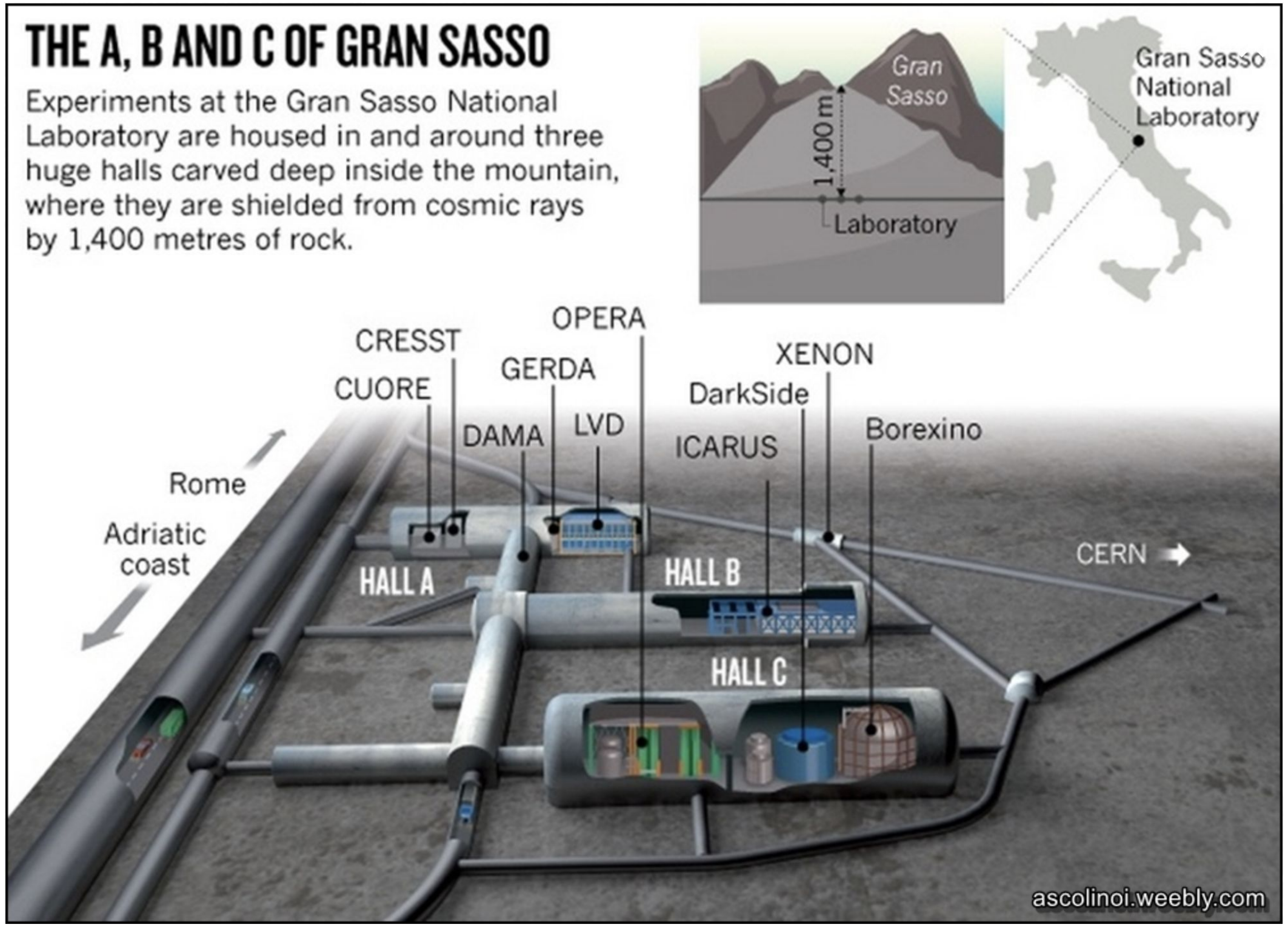
UNIVERSITÀ DEGLI STUDI DE L'AQUILA

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

PhD program

Astroparticle Physics

- The largest underground laboratory in the world devoted to the areas of particle physics, cosmology, and astrophysics;
- Used as a facility worldwide by scientists from 29 different countries;
- Around 1100 scientists;
- Research activities range from neutrino physics to dark matter search, to nuclear astrophysics, and also to earth physics, biology and fundamental physics.



From https://www.lngs.infn.it/en/lngs-overview

PhD program

Mathematics

- Applied Partial Differential Equations, Probability and Statistical Mechanics, Numerical methods and Continuum Mechanics modeling.

Regional Sciences and Economic Geography

- i) Inner Areas and Peripheral Development; ii) Disasters and Regional Resilience; iii) Human Capital, Migration and Local Labour Markets; iii) Culture, Tourism and Regional Urban Development; iv) Business, Innovation and Environmental Sustainability Within and Across Regions; v) Regional Policy Evaluation and Local Governance.

PhD program

Computer Science

- Interdisciplinary research on algorithms, formal methods, and software engineering.
- The Computer Science Group is the first computer science department in Italy in 2022 ranking ANVUR and national department of excellence.
- Additional positions and building autonomous systems, IoT, and algorithm-engineering laboratories.

PhD program

PHD CALL FOR APPLICATIONS 2023/24 NOW OPEN

- 10 scholarships for each program.
- Official language of the Ph.D. Programmes: English.
- Activities and Duration: The Ph.D. Programmes last four years.
- The Academic Year will start on November 1st 2023.
- GSSI awards scholarships until the dissertation defense and for a maximum of four years.
- The yearly gross amount of the scholarship is € 16.243,00. An additional 50% on a monthly basis may be awarded for research periods abroad if approved by the GSSI.
- Free accommodation on the first year at the guest house. From the second year on, a financial substitute of 350 Euros.
- Free lunch vouchers.
- A contribution of up to 1.200,00 euros for the purchase of a laptop for study and research purpose.

https://www.gssi.it/communication/announcements/item/21717-phd-call-for-applications-2023-24-now-open

PhD program

Requirements:

- English knowledge is compulsory.
- Applications are open to candidates in possession of one of the following degrees:
  - "Laurea Magistrale" or "Laurea Specialistica" or a four or five years degree.
  - a foreign University degree (minimum legal duration of the University course: four years). The eligibility of foreign degrees is assessed by the Selection Committee.
- Applicants obtaining their degree by no later than October 31, 2023 may apply.

Application

- Applicants must fill out the online application form (www.gssi.it/phd/), where it is possible to find all the necessary information for the submission, and attach the required documents by:
- May 30th, 2023, 3 pm (Italian time zone) for Astroparticle Physics, Computer Science, Regional Science and Economic Geography Ph.D. Programmes;
- May 2nd, 2023, 3 pm (Italian time zone) for Mathematics in Natural, Social and Life Sciences Ph.D. Programme.

PhD Programme	Interviews
Astroparticle Physics	June 12th to July 4th
Mathematics in Natural, Social and Life Sciences	May15th to June 2nd
Computer Science	June 12th to 28th
Regional Science and Economic Geography	June 12th to 28th

www.gssi.it/phd/

Postdoc positions

https://www.gssi.it/

- There is no fixed deadline.
- The last call was in December.
- Annual gross salary: € 45.000,00 renewable (gross amount before taxes).
- The duration of the appointment is 24 months.
- Contribution for the purchase of a laptop up to a maximum of € 3.000.

  Requirements:
- Applicants must hold a PhD degree or an equivalent qualification. The PhD title should be earned before starting the appointment.
- The application must include the following documents:

  • a curriculum vitae, including the complete list of publications;

  • a research statement;

  • up to three selected publications which will be evaluated individually. The PhD thesis can be included, since it is considered as a publication;

  • a valid ID document;

  • the candidate can also suggest the names of up to two external referees.

https://applications.gssi.it/postdoc

Review on Architectures in the Space Domain to support AI and DevOps: Midterm Findings & GSSI opportunities

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RQ4: How these architectures have been evaluated?

Study	Performed Validation	Comparison with other techniques
A1	Real project	✓
A2		
A3		
A4		
A5	Experiment	
A6		
A7	Case Study	✓
A8	Experiment, Simulation	✓
A9	Case Study	✓
A10	Experiment	✓
A11	Experiment	✓
A12	Simulation	
A13	Real project	

Study	Performed Validation	Comparison with other techniques
A14		
A15		
A16	Case Study	
A17	Experiment	✓
A18		
A19		
A20	Simulation	
A21	Simulation	✓
A22		
A23	Simulation	
A24	Experiment, Simulation	
A25	Experiment, Simulation	✓
A26		

RQ4: What are the main challenges to face when dealing with space domain restrictions?

Topic	Challenge
Environment	Wide temperature range, mechanical vibrations, vacuum and radiations.
Hardware	Limitations on size, weight, and power (SWaP), processing and memory
Communication	Limitations both on bandwidth and on directionality with lower-frequency RF systems
Culture	Risk-averse procurement behavior of the space industry leaves to long qualification process for space-grade components

RQ4: What are the main challenges to face when dealing with space domain restrictions?

Topic	Challenge	Description	Solution
Communication	Limitations both on bandwidth and on directionality with lower-frequency RF systems	Terrestrial systems are based on some degree of real-time interaction between two peers who might happen to be exchanging data. For space systems, this may or may not be the case. As one example, communication with Mars has a one-way propagation delay that is a few minutes in the best case. From a mathematical perspective, the major difference is that the space network model involves a temporal component than is not usually required when modeling a terrestrial network. Next generation space instruments are producing data at rates that strain the capabilities of current spacecraft to store data or transmit it to ground stations. As technology has improved, however, there have been incremental (albeit marked) improvements to each of the individual S, W, and P areas of radio performance. Improvements in computational architecture have led to the development of superior waveforms while simultaneously offering remarkable new platforms and approaches to radio design (e.g., software- defined radio, or SDR). At the link level, SDRs are now being employed to continually poll and reconfigure link parameters to operate at a point of maximum optimality.	Alternative protocols for these situations have been developed and are in use (e.g., Licklider Transport Protocol). Nowadays modular avionics technology has been applied in spacecraft platform and flash memory modules are incorporated in onboard computers e.g. satellite management unit (SMU) and data interface units (DIU). The more autonomous the satellites, the lower the cost of telecommunications and ground operations. The application of deep-learning concepts for on-board processing can enable spacecraft to efficiently process immense volumes of raw sensor-data into actionable data to overcome limitations in downlink communication. The optimisation of the algorithm for System-on-Chip platforms allows it to benefit from the best of a generic processor and hardware acceleration shall allow broader applications of these technologies with a minimum increase of power consumption.
Culture	Risk-averse procurement behavior of the space industry leaves to long qualification process for space-grade components	The enormous engineering costs and time associated with development of rad-hard libraries and processes, followed by lengthy qualification programs, result in over a decade of delay before space-grade parts are available for integration into space systems.	To address these challenges, architectures design has been updated to include highly-reliable radiation-hardened computing resource that supervises a diverse collection of commercial processors such as multi-core general purpose processors, FPGAs, and GPUs, where each constituent architecture can be called upon to support the applications for which it is best suited.