SpaceCubeX2:
Heterogeneous On-board Processing for Distributed Measurement and Multi-Satellite Missions

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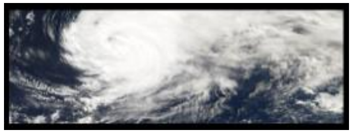
Earth Science Technology Office

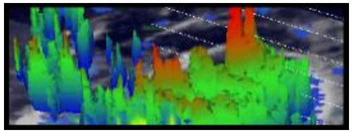
Background

- Prior research showed that heterogeneous computing could yield a 20-20,000x increase in on-board computing capability
- Sufficient for
  - Global, continuous observations
  - Supporting higher fidelity instruments up to 10^{11} bps
  - Low-latency data products
  - Cross cutting global climate change, air quality, ocean health, ecosystem dynamics …

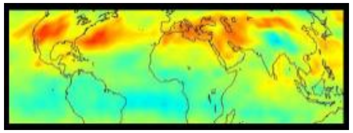


ACE

GEO-CAPE



3D-Winds



ASCENDS

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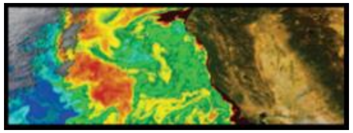
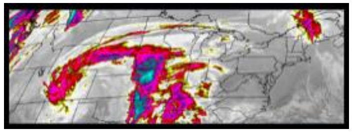


PACE

TSIS-1

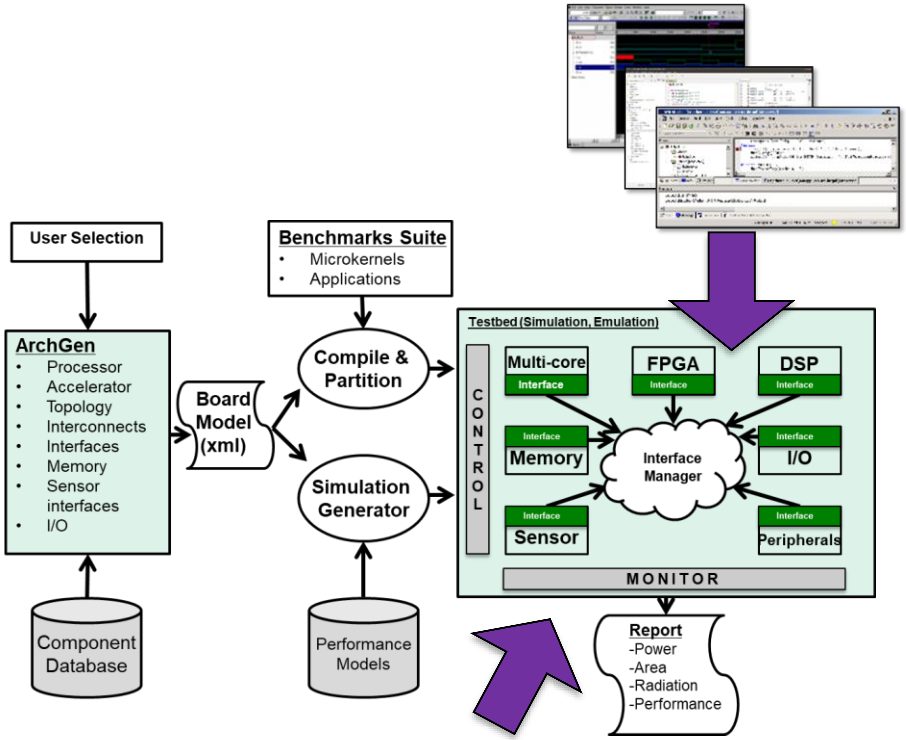
LIST



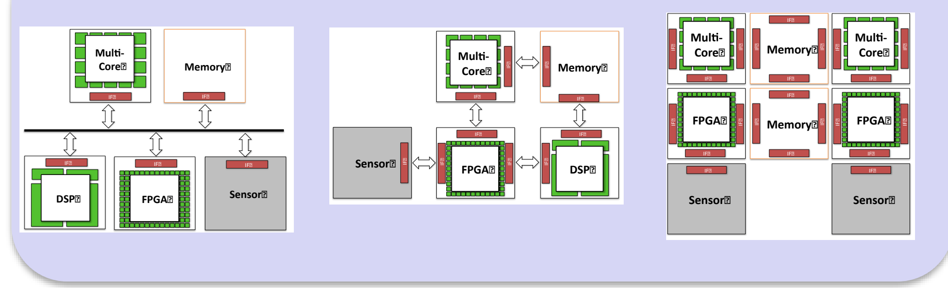
PATH

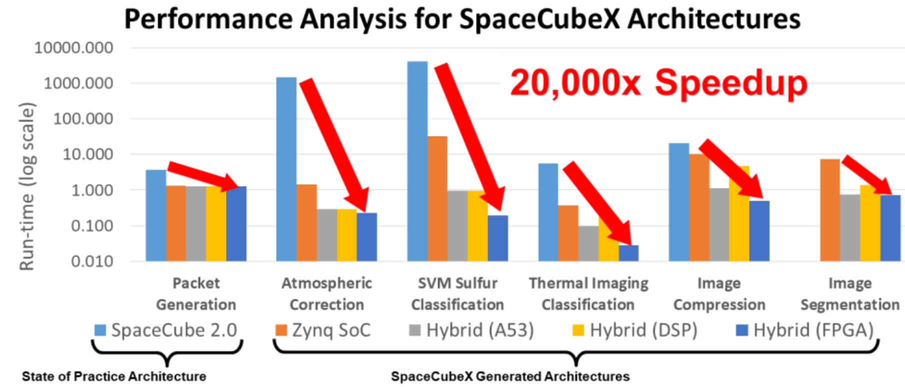
AIST-14: Onboard Computing Analysis Framework

Simulation Platforms

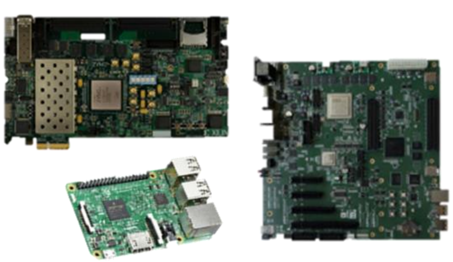


Board Topology Candidates

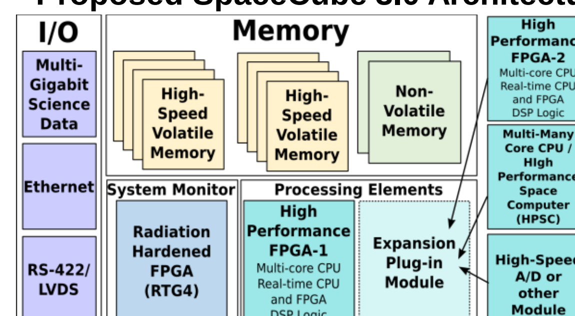




Emulation Developer Board Platforms



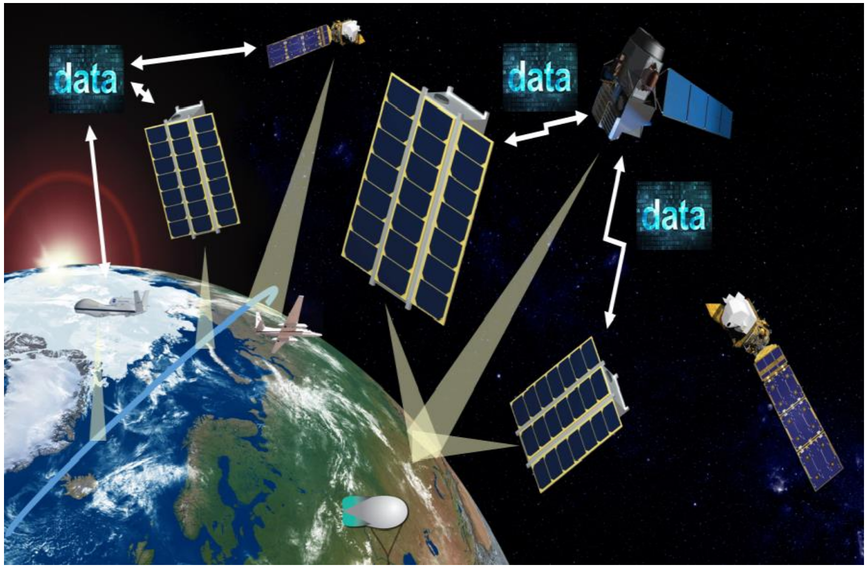
Proposed SpaceCube 3.0 Architecture



End to end tools which enable rapid, accurate exploration of on-board

New Challenges

- 2nd National Academy of Science Earth Science Decadal Survey
- Satellite constellations
  - Increased temporal sampling
- Multi-sensor and platform coordination
  - Distributed sensing
- Intelligent Sensors
  - Autonomous reaction to events
  - Self preservation

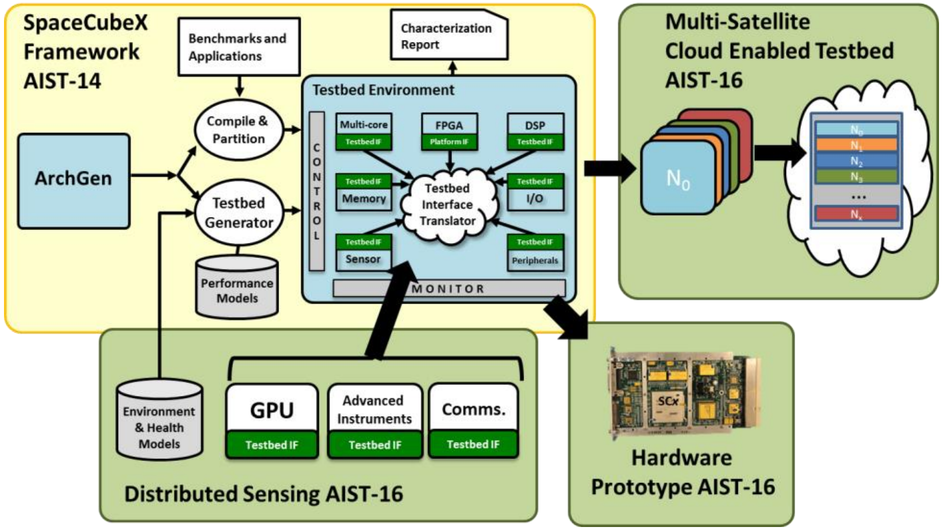


Multi-satellite, Multi-sensor Mission

- How can on-board computing support these new challenges?

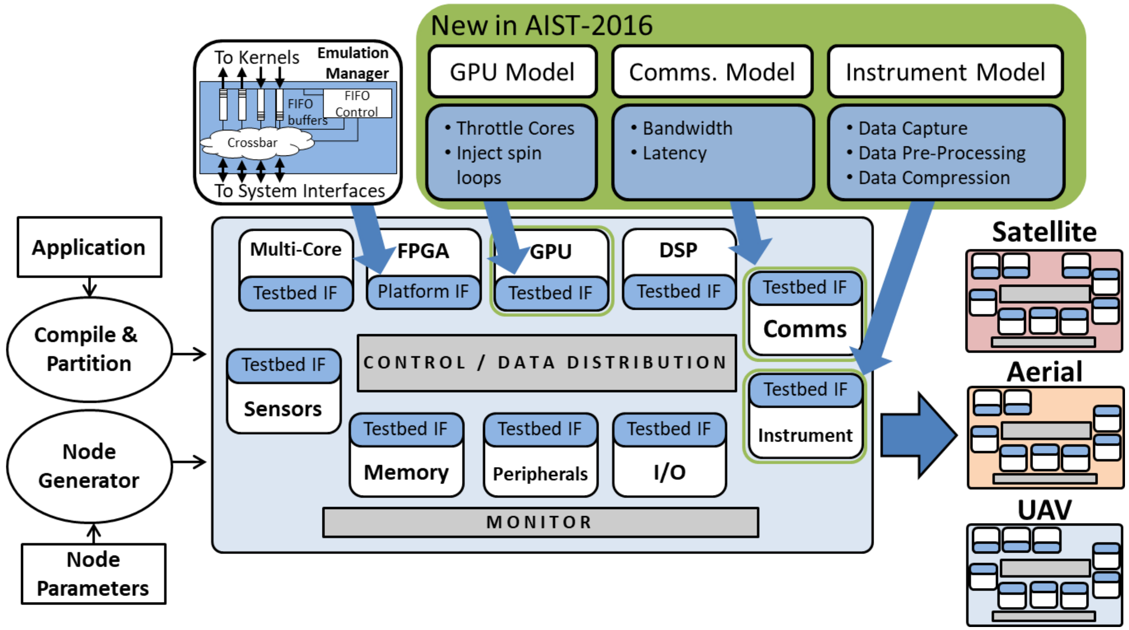
AIST-16 Approach

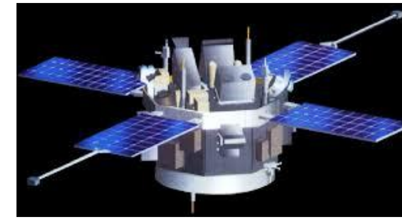
- Extend the AIST-14 SpaceCubeX On-board computing Analysis Framework to support analysis of new mission goals
- Benefits
  - Accessible, rapid prototyping of next generation satellite and **multi-satellite constellations** capabilities via virtual machines deployed in a cloud computing environment.



  - A proto-type heterogeneous on-board computer for experimentation of advanced autonomy and control capabilities required by intelligent instrument control and constellation management.
  - **Accelerate migration** of missions from UAV and airborne platforms to satellites to support distributed sensing.
  - Accurate, scalable approach to **assessing Multi-Satellite mission performance**.
  - Detailed analysis and initial run-time implementation of FluidCam Fluid Lensing, MiDAR, Diurnal Measurements, and Mult-Angle Measurement applications.

Distributed Measurement Architecture





New capabilities

1) GPU co-processor support to model airborne and UAV platform processing capabilities

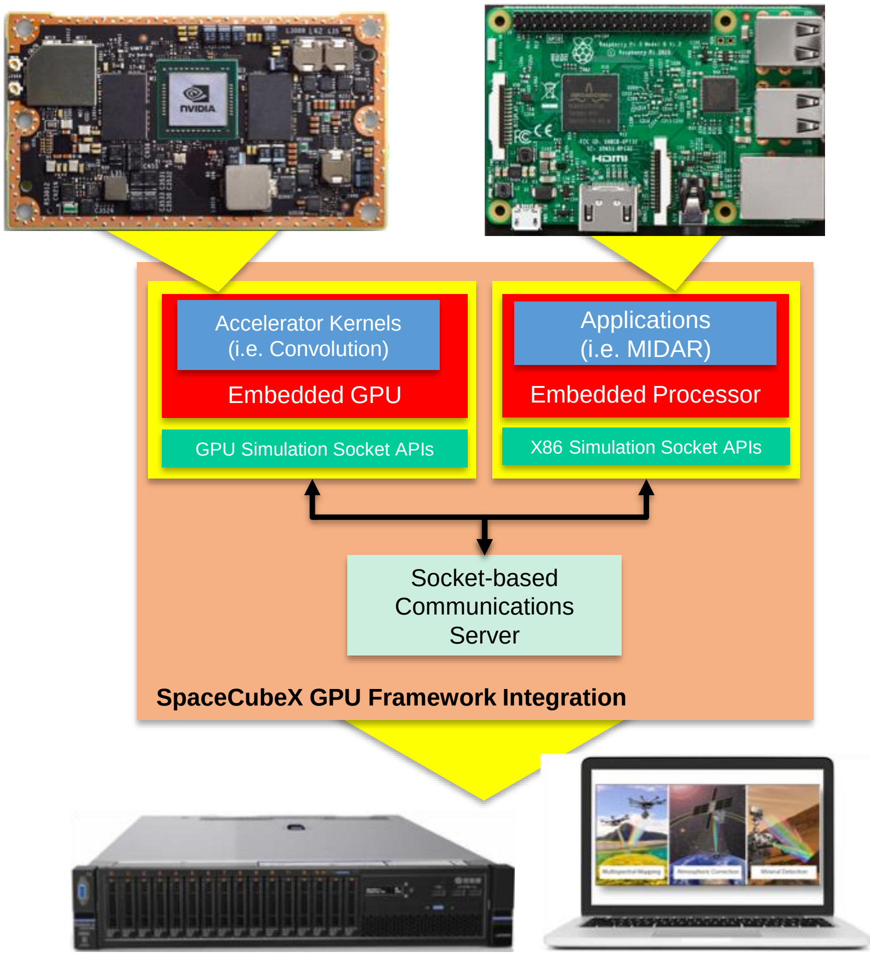
2) Environment and instrument health modeling for intelligent instrument capabilities

3) Enhanced the communication modeling for multi-node scalability

SpaceCubeX GPU Integration

- Extended SpaceCubeX Framework to incorporate GPUs as co-processor
  - Based on FPGA co-processor simulation socketed model
  - Support for CUDA-based GPU accelerators
- Socket API ported to GPU hosts (Linux and Windows run-time environments supported)
- Development enables GPU “simulation” environments on Server-grade GPUs
  - Suitable for workstation development or Cloud integration
  - Decouples dependency on embedded GPU platform
- Currently support Nvidia Tesla GPUs and Nvidia TX2 Embedded GPUs
- GPU kernels tested in SpaceCubeX environment

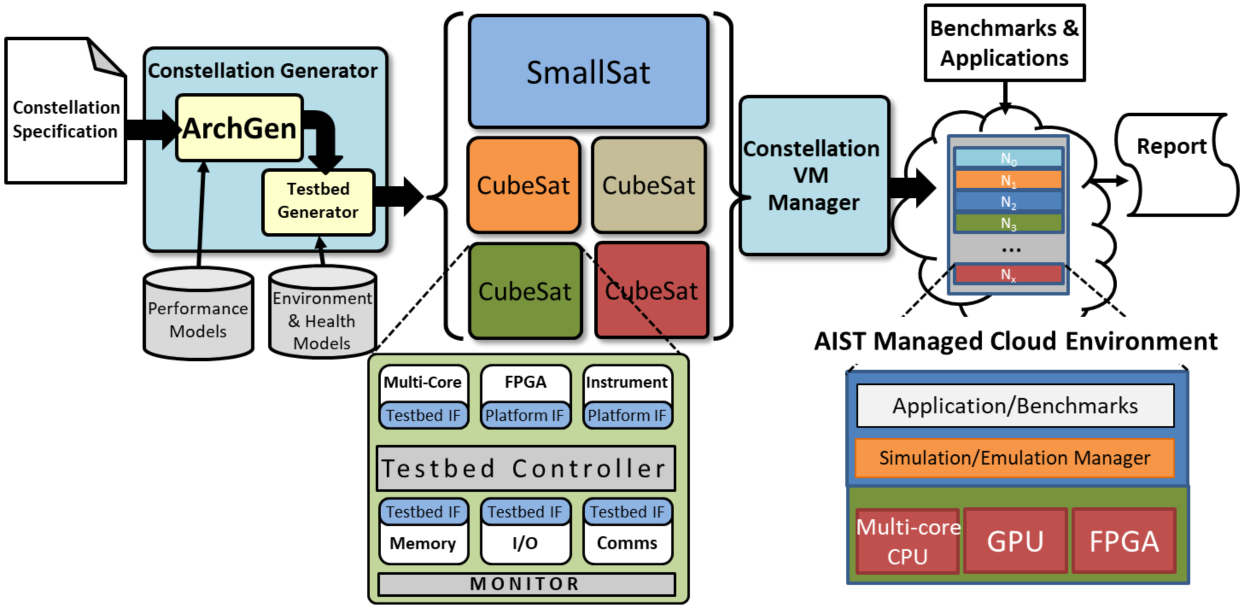
Emulation with Embedded GPUs



Simulation with Server-Grade GPUs or Laptops with Mobile GPUs

Multi-Satellite Missions

Onboard Computing Analysis Framework Extensions



Amazon F-1 Instance

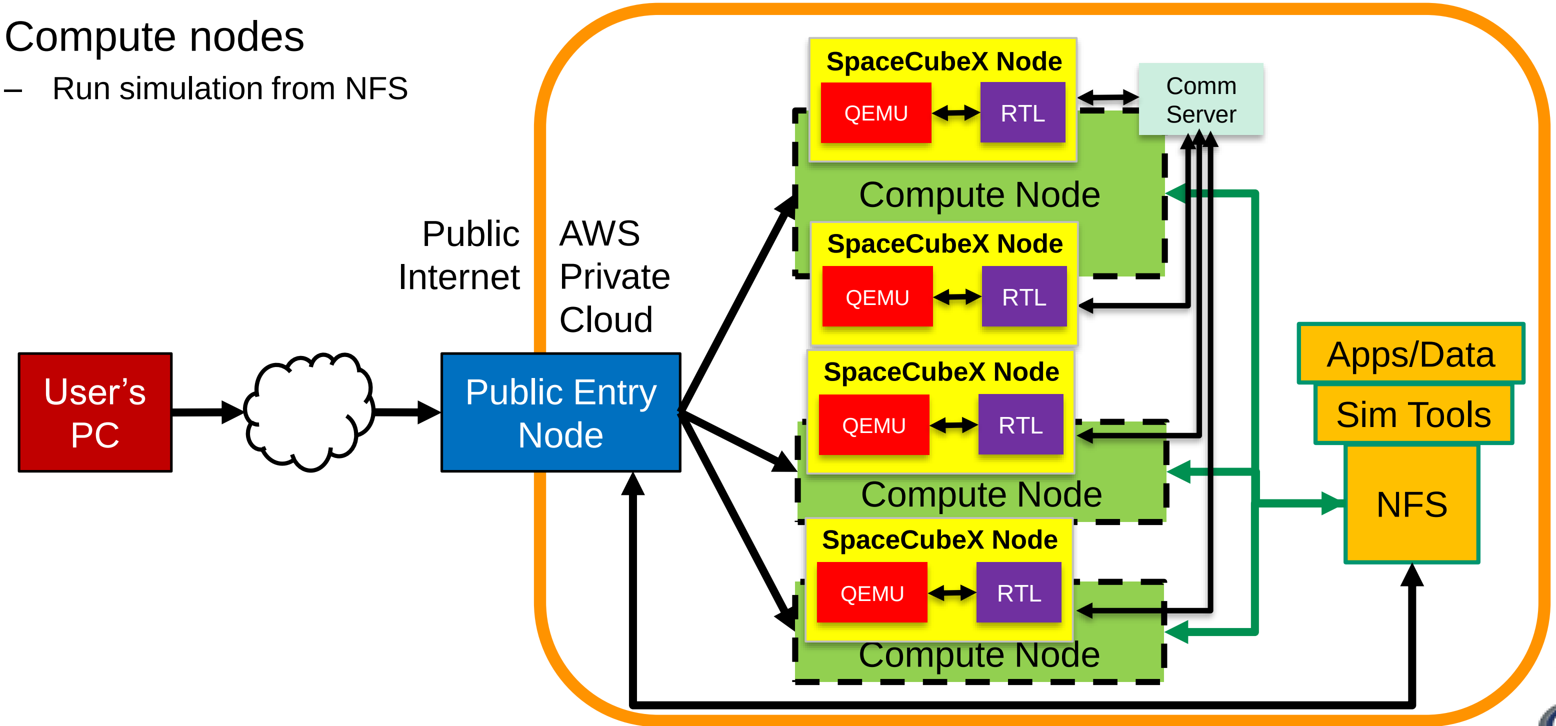
- Deploy SpaceCubeX Framework as a VM cloud instance(s)
- Spawn constellations in the cloud
- Parallelizes workload
- AWS F-1 Enables hardware emulation
- Easier technology transition for external users

AWS Cloud Simulation Infrastructure

Goal: To virtualize existing multi-platform simulation environment to scalable cloud

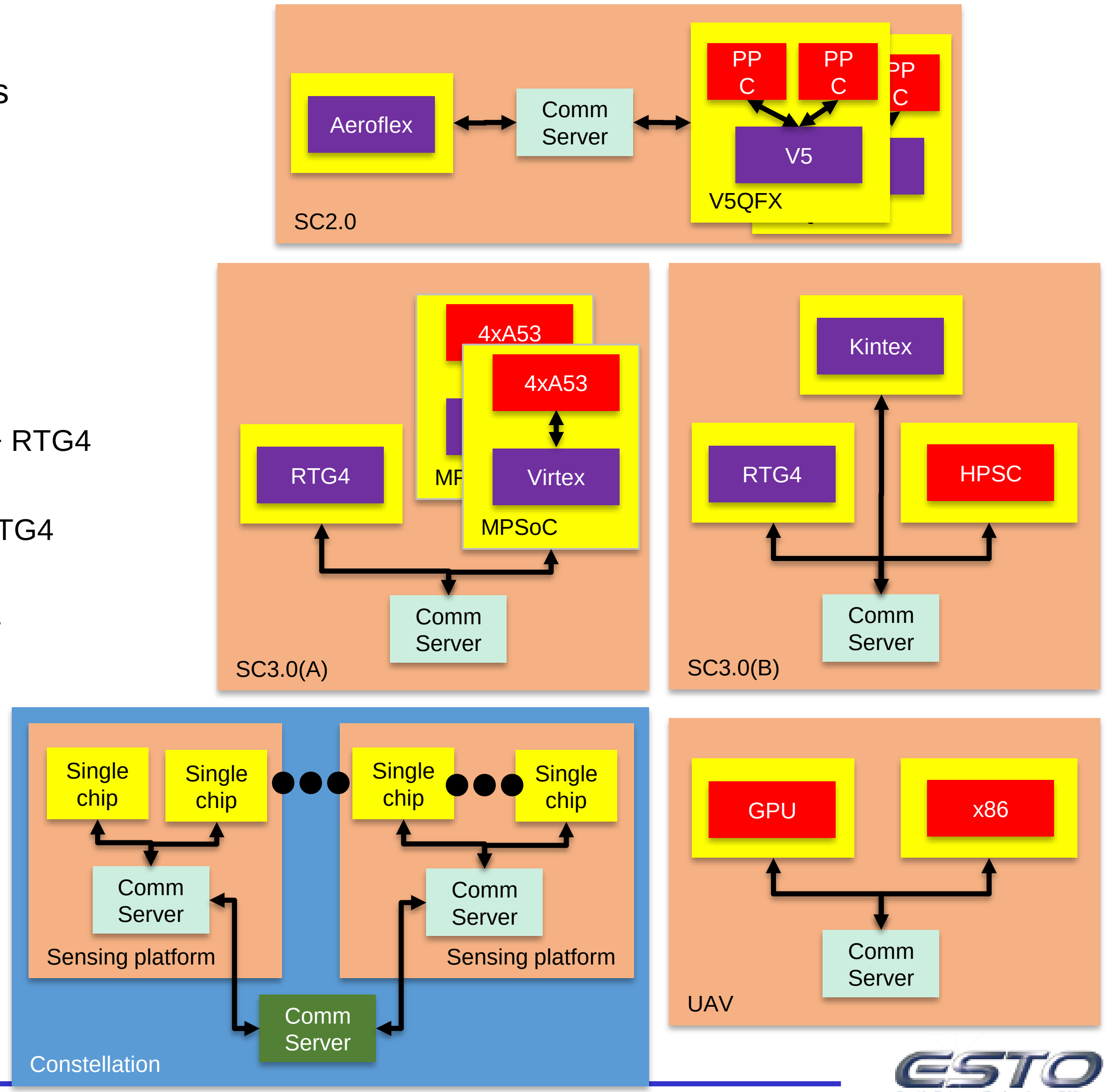
- Public Entry node – always available (small/cheap/T2.micro instance)
  - Users log into this node
  - ***Compute Nodes*** are launched from this node
- NFS – Network File System
  - Contains tool installations necessary for simulation
  - Application code and data
  - Accessible by all compute nodes
- Compute nodes
  - Run simulation from NFS

Status: Hardware simulation capability running. F-1 emulation in progress.



Platform Targets

- User Defined
  - Xilinx and Microsemi FPGAs
  - ARM and PowerPC CPUs
- SpaceCube 2.0
  - Aeroflex FPGA
  - 2x V5QFX (V5,2xPPC)
- SpaceCube 3.0
  - Variation A
    - 2x MPSoC (US+,4xA53) + RTG4
  - Variation B
    - 2x Zynq (Kintex,2xA9) + RTG4
  - Variation C
    - KintexUS + HPSC + RTG4
- UAV / Airborne
  - X86 + GPU
- Constellation
  - SpaceCube 2.0
  - SpaceCube 3.0
  - HPSC
  - UAV
  - Others

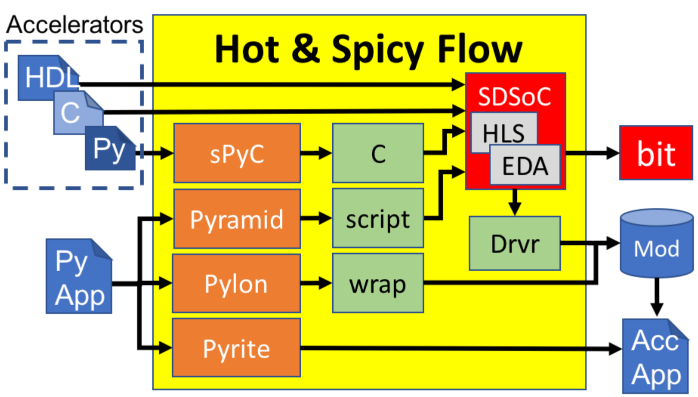


Hot & Spicy – Accelerating Mapping Python Applications to FPGAs

Motivation: ARC implementation of MiDAR in Python

Goal: Accelerate important Python functions by leveraging existing EDA tools (HLS)

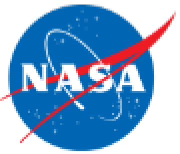
- Developed Framework to accelerate Python Apps
  - Open-source release at https://github.com/ISI-RCG/spicy
- Targets SoC+FPGA systems where App can be Python
- Cross-compiles Python function to C, accelerates with HLS
- Automates system generation, drivers, integration



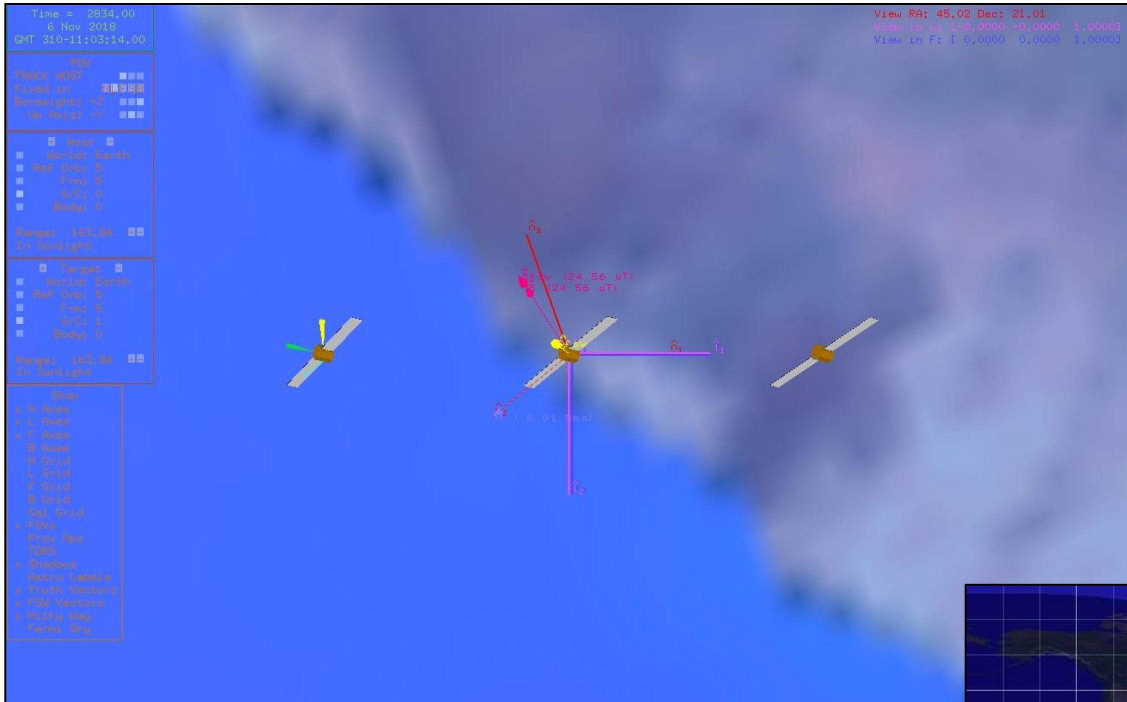
Canny Edge Detection from Earth Science Benchmark

39,137x performance gain over original Python
6x gain over optimized OpenCV

Reduces application mapping time from Months to Hours, enabling rapid exploration of optimization paths



Constellation Definition: 42 Integration

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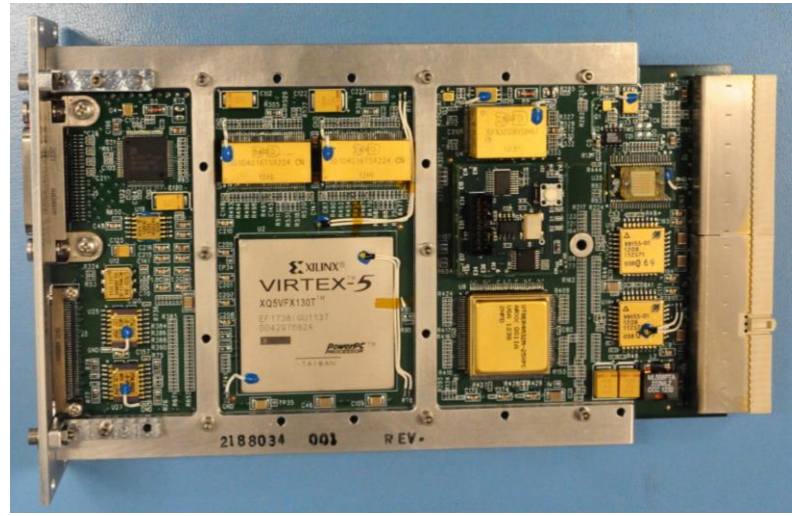
GSFC's 42: General Purpose Multi-body, Multi-Spacecraft Simulation

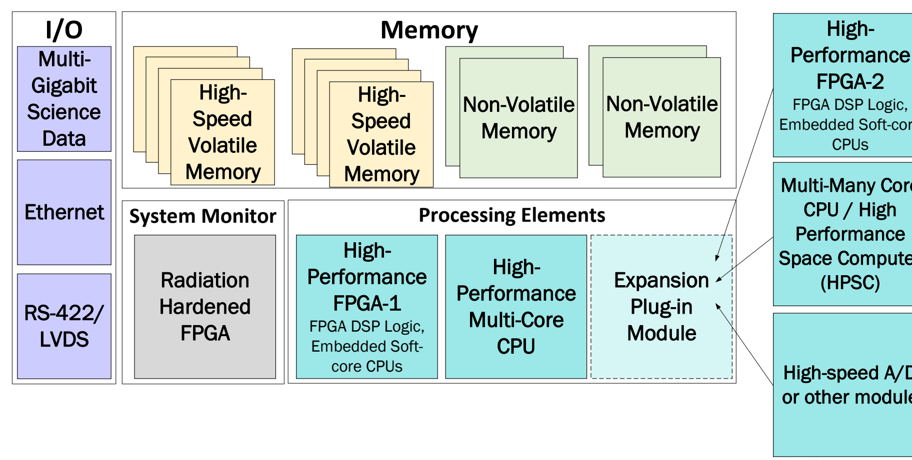
- Provides multiple satellite flight models that can coordinate with SpaceCubeX2 simulation/emulation environments to more accurately model flight scenarios.
- Environmental models, instrument models, flight models, and compute models integrated into SpaceCubeX2

SpaceCubeX2 Hardware Prototype Goals

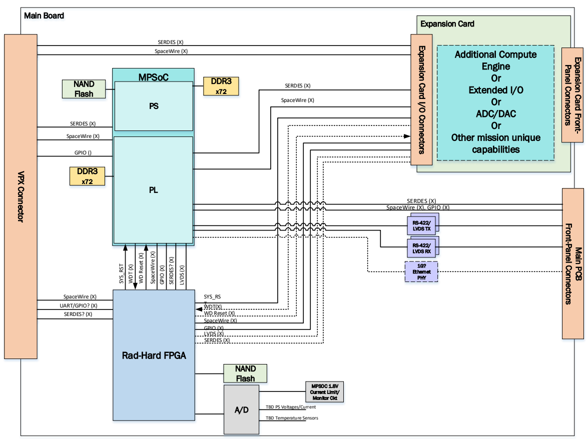
- Advances TRL
- Higher fidelity experiments
- Realistic capture of “ad-hoc” processing required for intelligent instruments
- Demonstrate technology to facilitate transition and adoption
- Xilinx MPSoC no longer a viable option for the hybrid device due to radiation performance

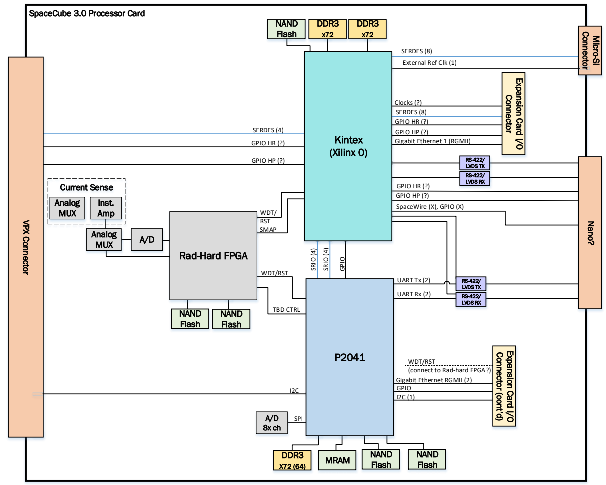


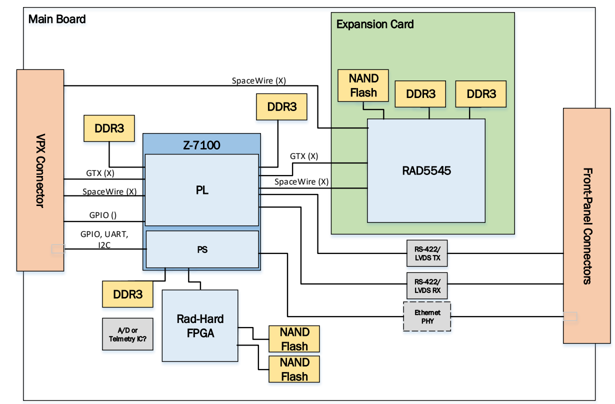
Proposed SpaceCube 3.0 Architecture

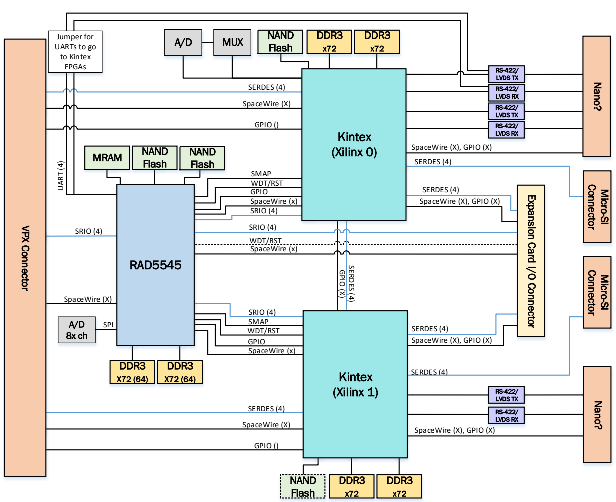


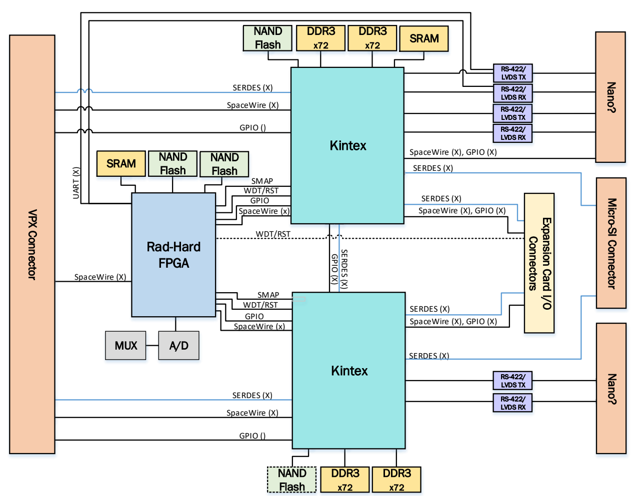
Traded a Variety of Architectures

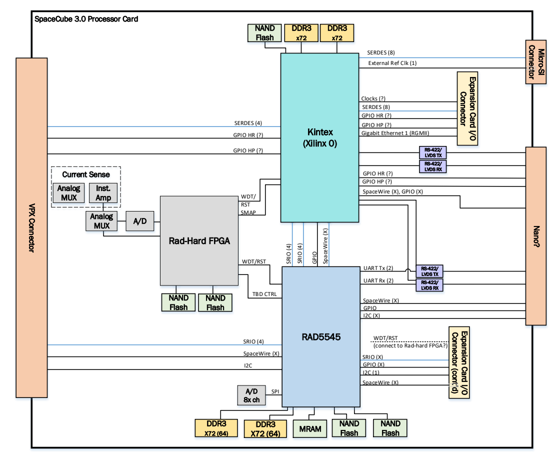












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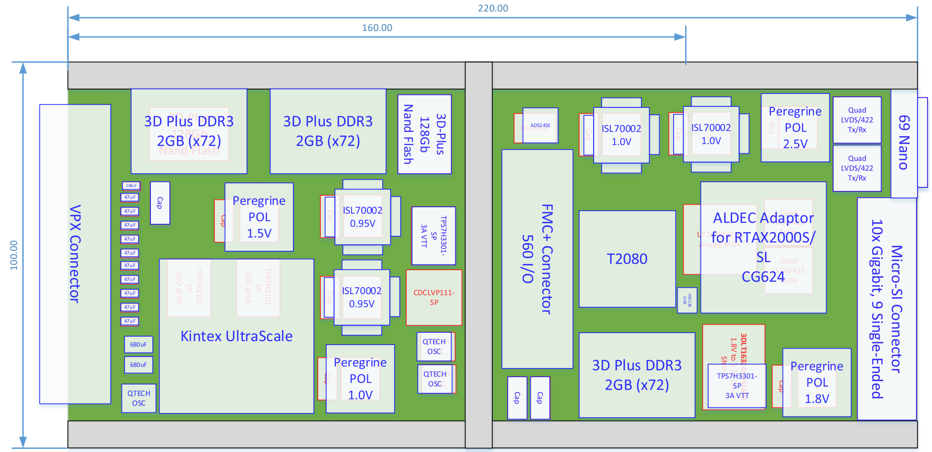
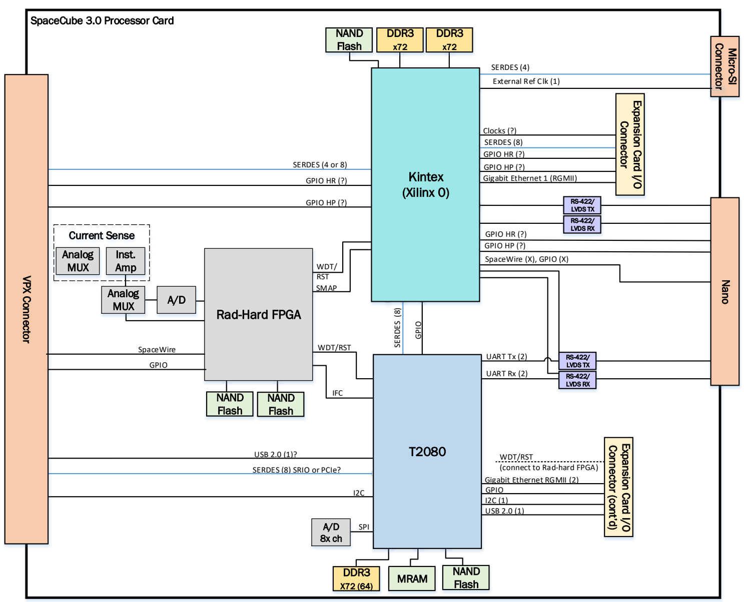
SpaceCube v3.0 Block Diagram and Layout Study

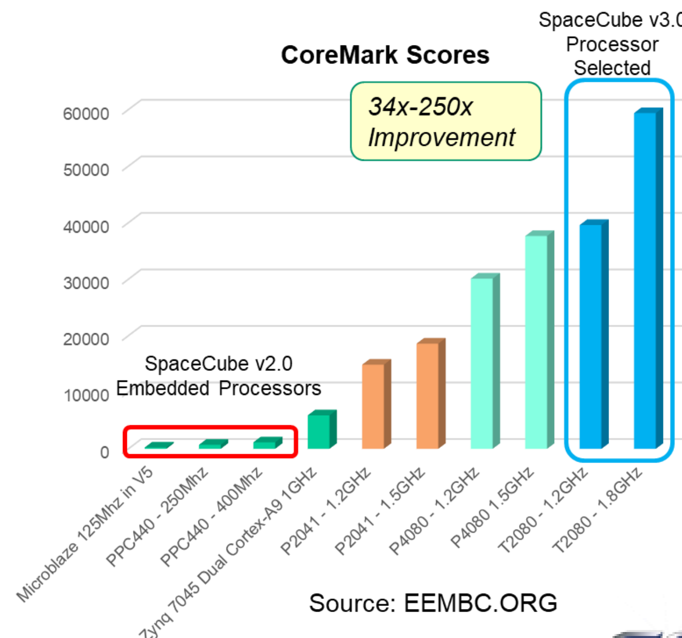
- **NXP T2080 Multi-core processor** + Xilinx UltraScale
- Previous generation P-series processors (P2020,P4080) being used on a several flight computers – SpaceMicro Proton 400K, Franhoffer Fokus
- T2080 Main Features
  - 64-bit Quad-Core PowerPC (8 virtual cores)
    - Up to 1.8GHz operation
  - Altivec SIMD
  - 16 Multi-Gigabit transceiver lanes
  - DDR3/3L interface with ECC – 600MHz-1067MHz rate

SpaceCube 3.0 Prototype Area Study



Block Diagram





FluidCam and Midar Case Studies: Computational Analysis

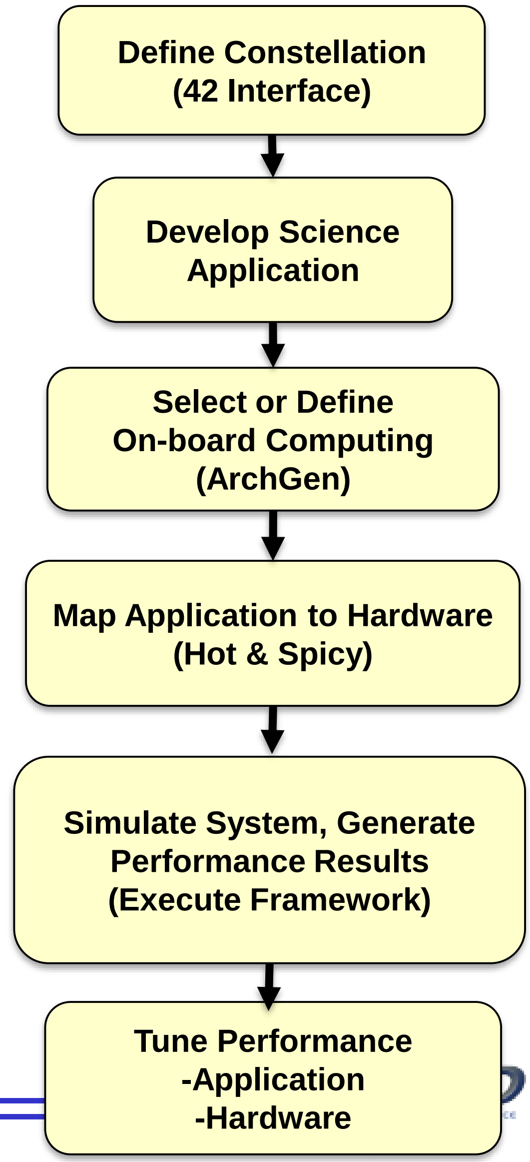
Instrument	Data Rate	Real-time Compression Rate Required	Platform Max Throughput (Airborne)	Max Throughput (Space)	Spaceborne Increase Requried
FluidCam	472 MB/s	4.1 GOP/s	400 GOP/s @ 40W	57.6 MOP.s @ 10W	71.2x
MiDAR (7ch)	8.8 GB/s	87.5 GOP/s	400 GOP/s @ 40W	57.6 MOP.s @ 10W	1,519x

- Initial analysis shows significant spaceborne processing increase required even for standard compression scenario
- Goal to perform more complex processing on-board as well
- Profiled and partitioned code. Currently accelerating image intensity calculations on GPU using: (i) Tensorflow, (ii) Numba, (iii) custom CUDA kernels

Summary

- Developing framework to evaluate on-board processing requirements for emerging multi-satellite missions
- Additions
  - GPU support
  - AWS support
  - Simplification of mapping to heterogeneous hardware
- Next
  - Constellation definition
  - Environmental & Comms models
- Great! So how can I use it?
  - Contact us! mfrench@isi.edu

SpaceCubeX Flow



QUESTIONS?

18