A Preliminary Implementation of the F' Framework for Managing Machine Learning Applications

Bronco Space

California State Polytechnic University, Pomona

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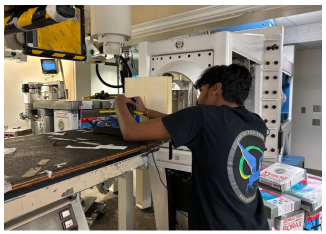
About Bronco Space

- Bronco Space is a mostly undergraduate student organization at Cal Poly Pomona.
- Founded in 2019, Bronco Space has run the entire gamut from starting at zero to becoming the leading space technology group at Cal Poly Pomona.
- Bronco Space has engaged in multiple NASA funded instrument development projects. Average time for TRL 3 to TRL 6 is 10 months.

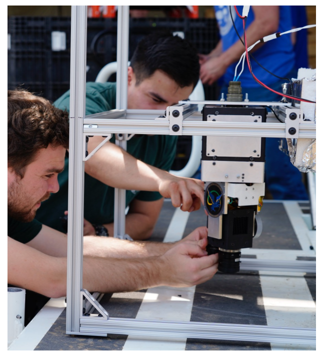
Providing a Path to Flight

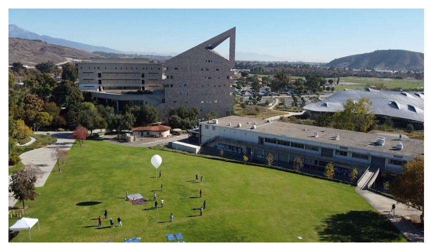
Laboratory Research and Development



- Technologies are created by students in the laboratories and tested in simulation environments.
- These technologies are then made into fully developed prototypes.

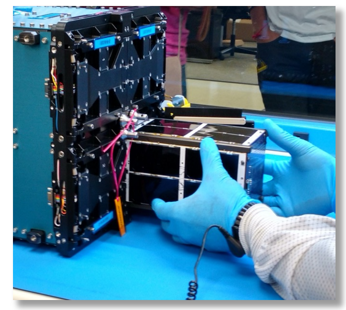
Sub-Orbital Testing

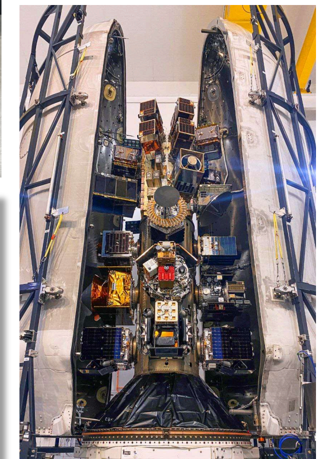




- Bronco Space has extensive experience conducting sub-orbital test campaigns.
- High altitude balloons and rocket power landers for TRL6 tech validation.

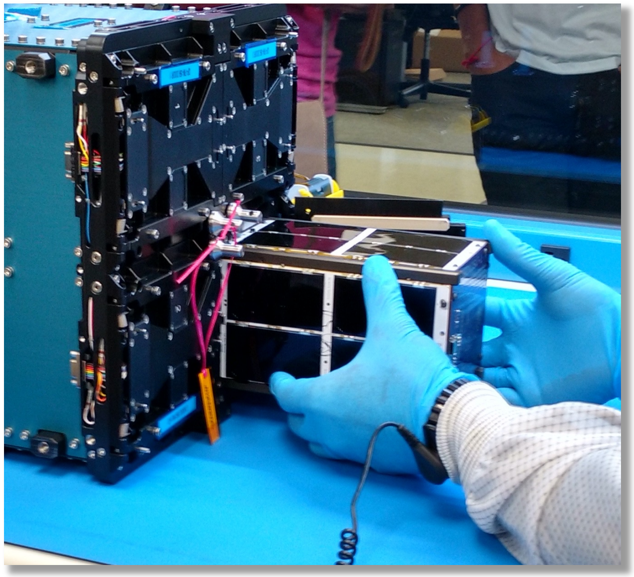
Orbital Launches

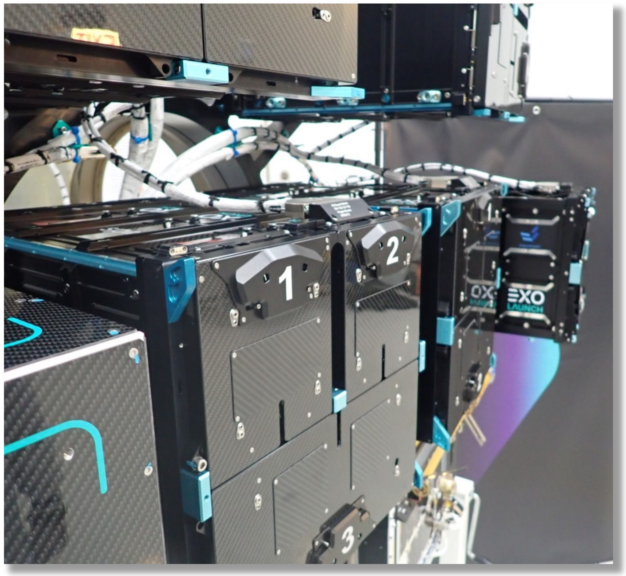




- Four CubeSat launches conducted in the last two years.
- Qualification testing, launch services, and mission operations through commercial and university partners.

Bronco Space's Satellites

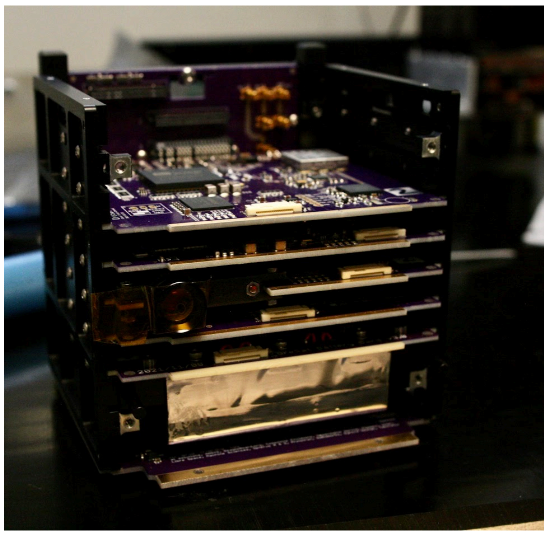




- In the last calendar year our organization has delivered three unique CubeSats for launch to LEO, all on commercial launch services. Our first CubeSat was launched in Summer 2022.
- The satellites have trended to be significantly cheaper and faster with each iteration.
- Our current efforts are focused on applying machine learning algorithms to space technologies.

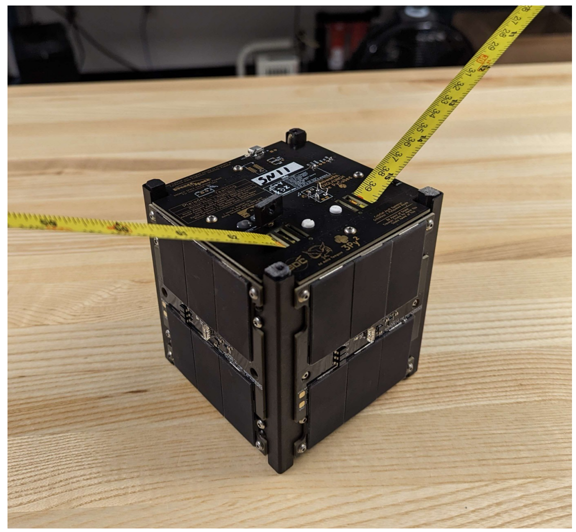
Software on the Three US Open-Source CubeSat Platforms

OreSat



- Modular Card Cage System.
- Custom flight software for each mission running on ChibiOS.
- Resilient but high cost.

PyCubed / PROVES

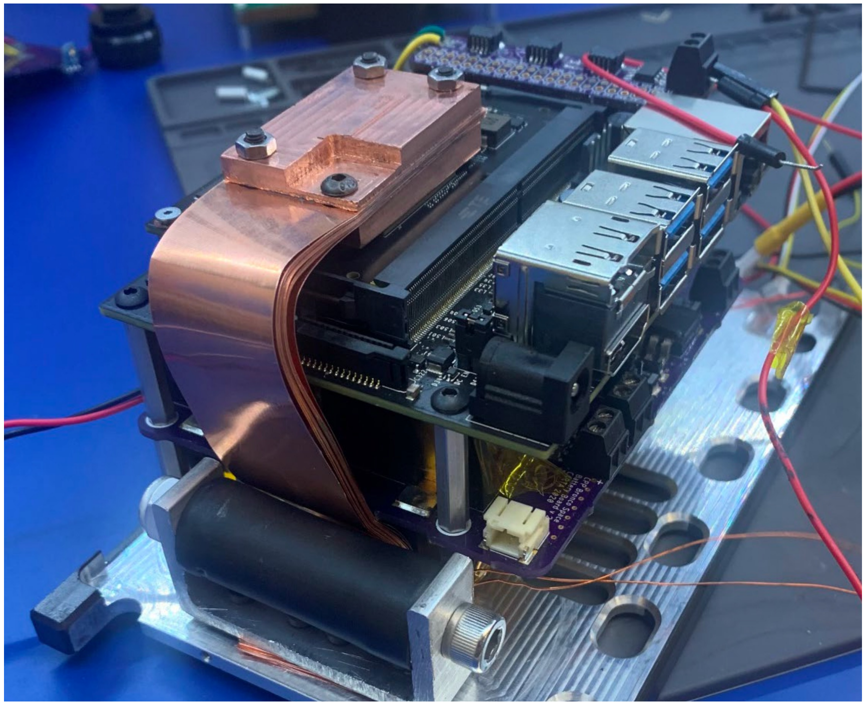


- Single Board Computer architecture.
- Simple state machine in Circuit Python.
- Less resilient but very low cost.

Artemis CubeSat Kit

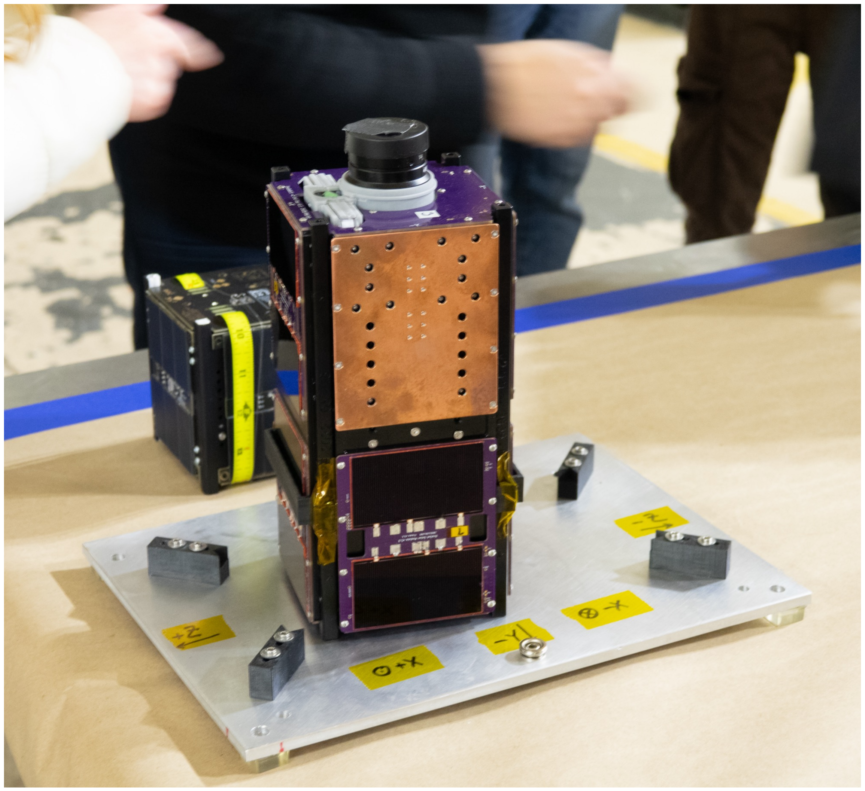
- Most traditional CubeSat architecture.
- Formerly COSMOS but now F’.
- Heavily supported by NASA.

What is SCALES?



- Spacecraft Compartmentalized Autonomous Learning and Edge Computing System (SCALES)
- Robust, adaptable, and rapidly deployable flight computer framework for implementing AI/ML decision-making systems on spacecraft.
- An integrated hardware / software system that creates a reusable environment for the execution and training of Machine Learning (ML) algorithms on-orbit.
- Path towards creating a safe, robust, and adaptable software environment to implement various ML/AI algorithms in orbit, enabling greater autonomy for existing space systems.

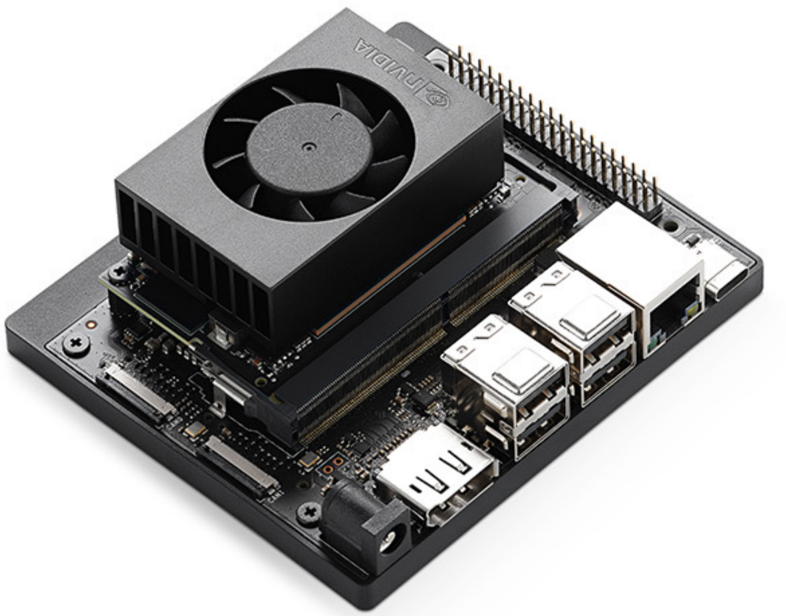
Why Are We Making SCALES?



- More than 2,300 small satellites have launched worldwide.
- Compact, cost efficient, and experimental.

- Physical and budgetary constraints necessitate compromises.
  - Diminished High-bandwidth downlinks
  - Smaller operations teams
- Heightened need for autonomous functionality to address physical and fiscal constraints

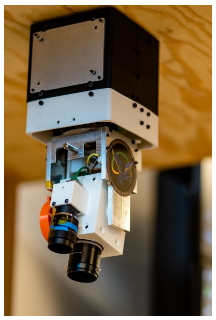
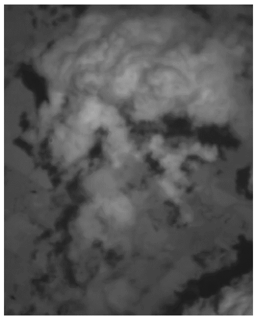
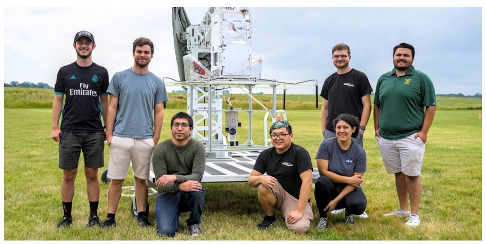
SCALES Mission



An integration between a Commercial Off the Shelf (COTS) edge computing hardware, that enhances on orbit computing, and a reusable software architecture, that provides reliability and mission assurance.

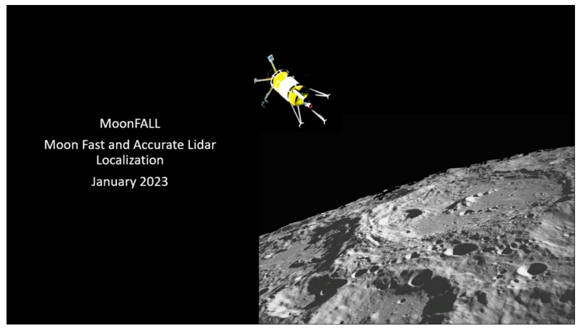
Pedigree for Using ML Models on Spacecraft

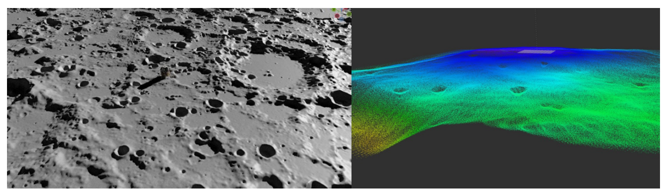
Bronco Ember

- Autonomous Wildfire Detection System
- Computer Vision and Edge Computing for Autonomous Remote Sensing

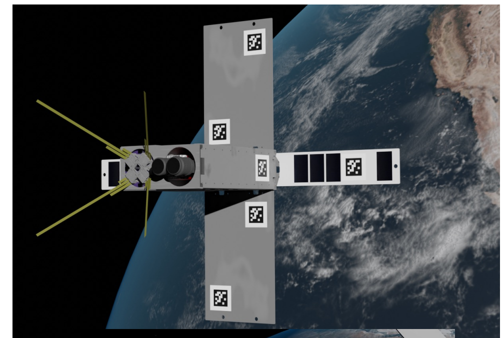
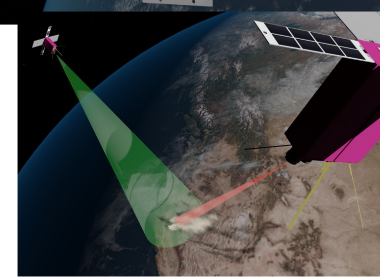
MoonFALL





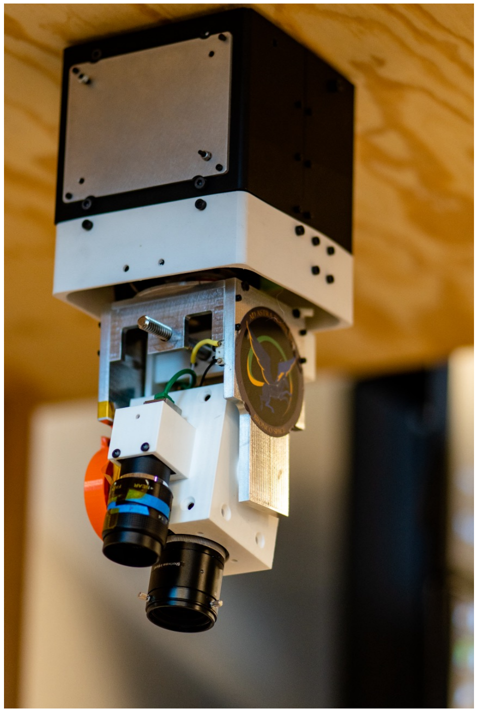
- Autonomous mapping, precision landing, and hazard avoidance system.
- ML model trained in a digital twin and tested sub orbitally

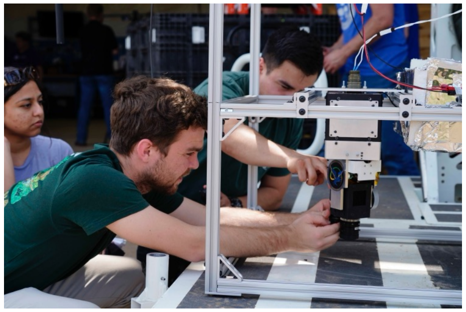
Autonomous Satellites

- Autonomous operations for Spacecraft conducting Rendezvous & Proximity Operations and Autonomous Observation.

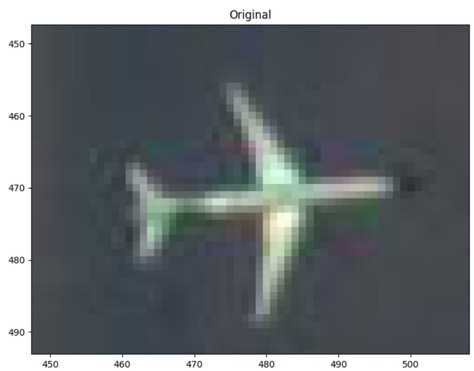
Use Case Study: Bronco Ember



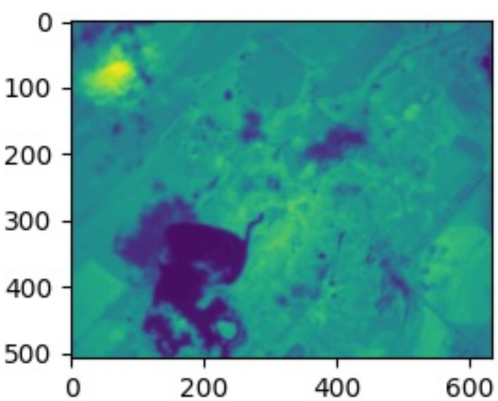


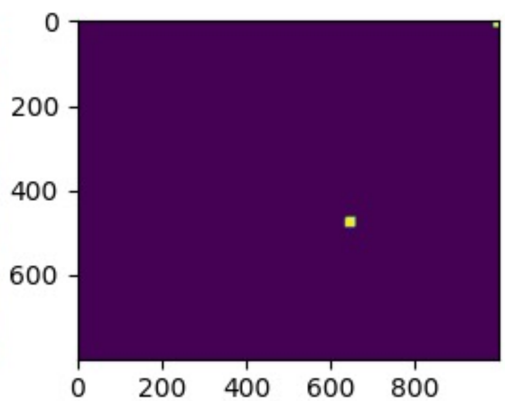
- Bronco Ember Autonomous Wildfire Detection Instrument
- Requires Human tagging of data for models
- Real-time fire prediction model and on-board analysis of data for autonomous search and track of nascent wildfires.

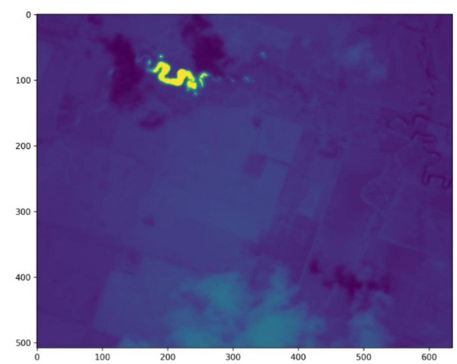
Use Case Study: Bronco Ember

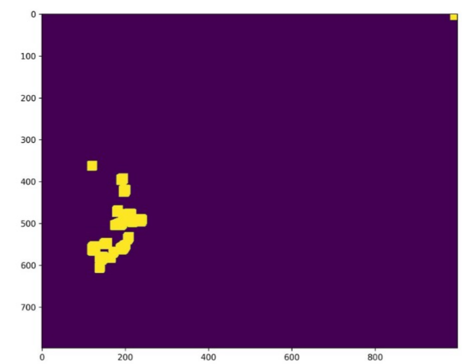


- Running this sort of detection software on remote platforms can be valuable for autonomous notification and re-tasking.
  - Downlink of images would require minutes to complete. A notification message is milliseconds.
- Current implementation is undynamic and requires close monitoring while using the model outputs as feedback into the control system.

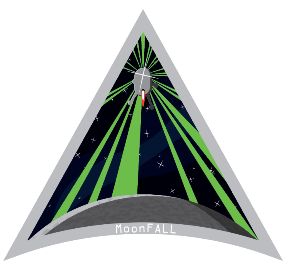






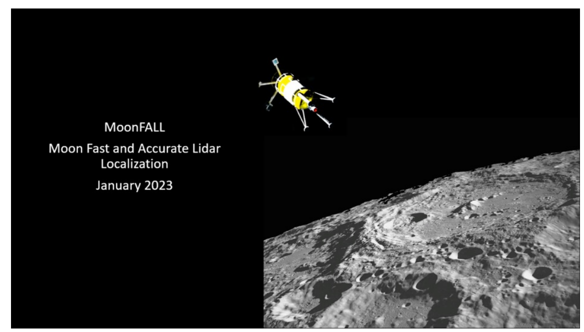


Use Case Study: MoonFALL

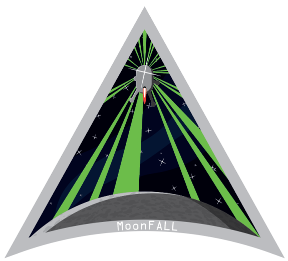


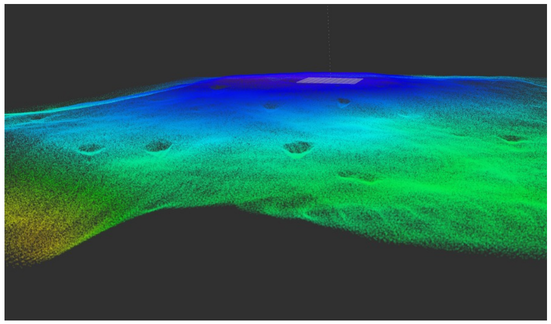
Picture Credit: Masten Space

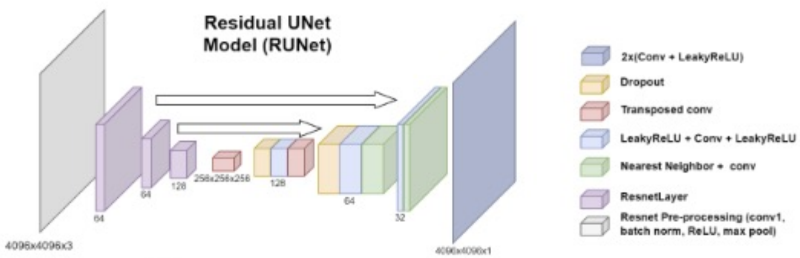
- MoonFALL: Moon Fast and Accurate LiDAR Localization
- Machine Learning model used to generate a lunar terrain map during a nighttime precision challenge.
- Rapid inference is required to ingest the LiDAR and visible camera data streams within the time constraints.

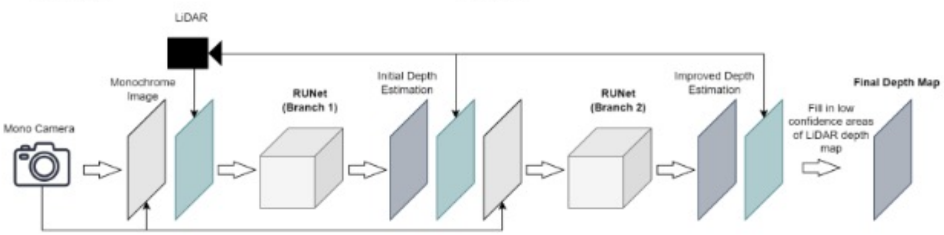


Use Case Study: MoonFALL

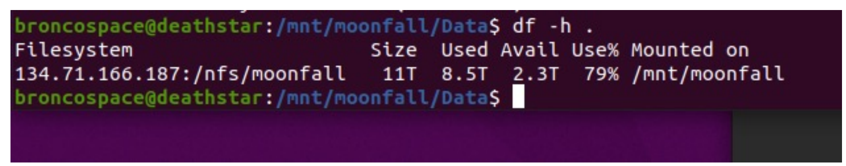








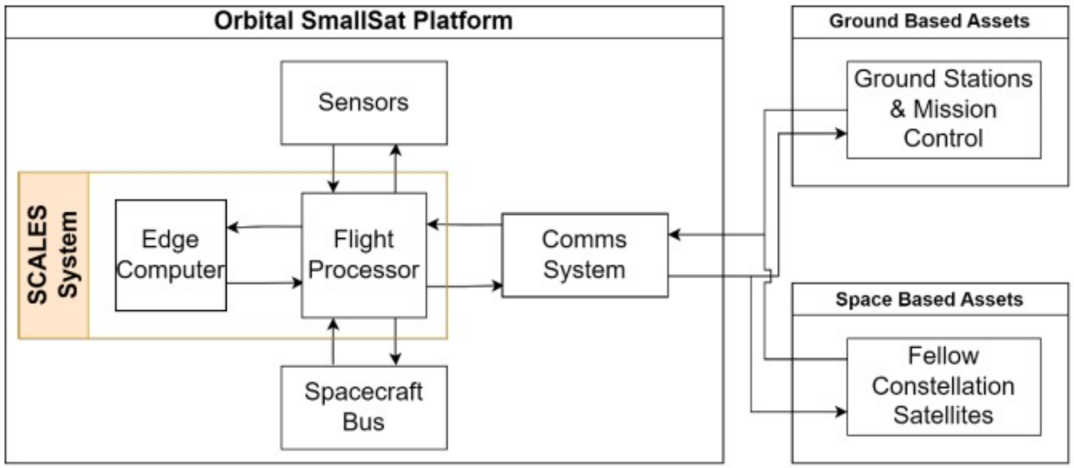
- MoonFALL Training models depend on millions of simulated terrain data.
    - 20MP Cameras, Lidar point clouds
    - 10 seconds landing simulation generates 5 GB of training data.
- 200,000 photos + lidar samples 8.5 Terabytes of data.
    - Requires weeks of training per batch.
- Training is better done in situ than saved, transferred, and processed.



Machine Learning in a Space Environment with F’

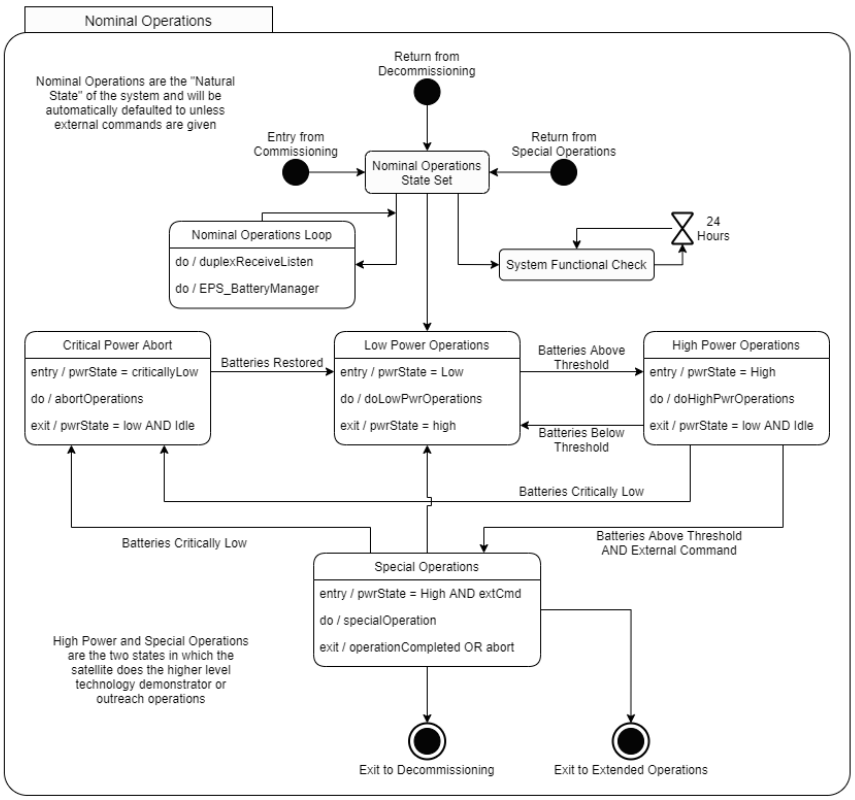
- Survival of the Space Environment
- Emphasis on Safety and reliability
- Allows for easy integration of new functionalities without compromising the performance of existing features.

- Quick reuse of core functionalities, saving engineering time to generate Source Lines of Code (SLoC) and perform testing and verification.



- Open-source satellite development and investigations into low cost rapidly deployed systems.

Example of Simplified CubeSat Software

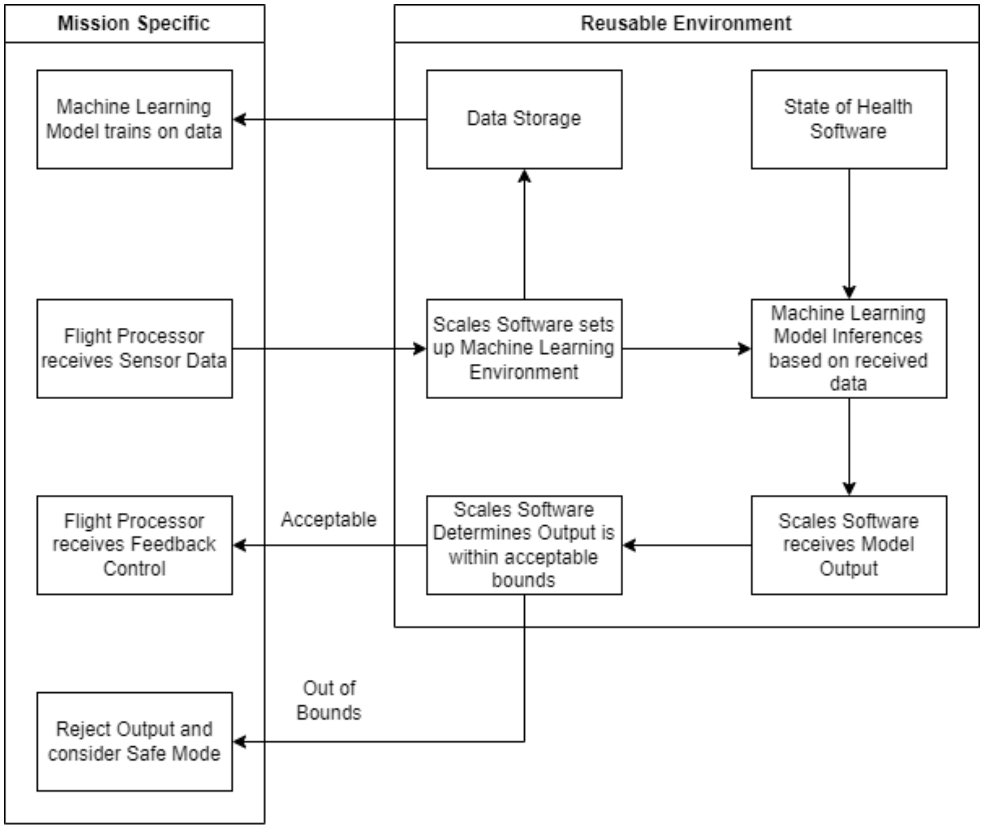


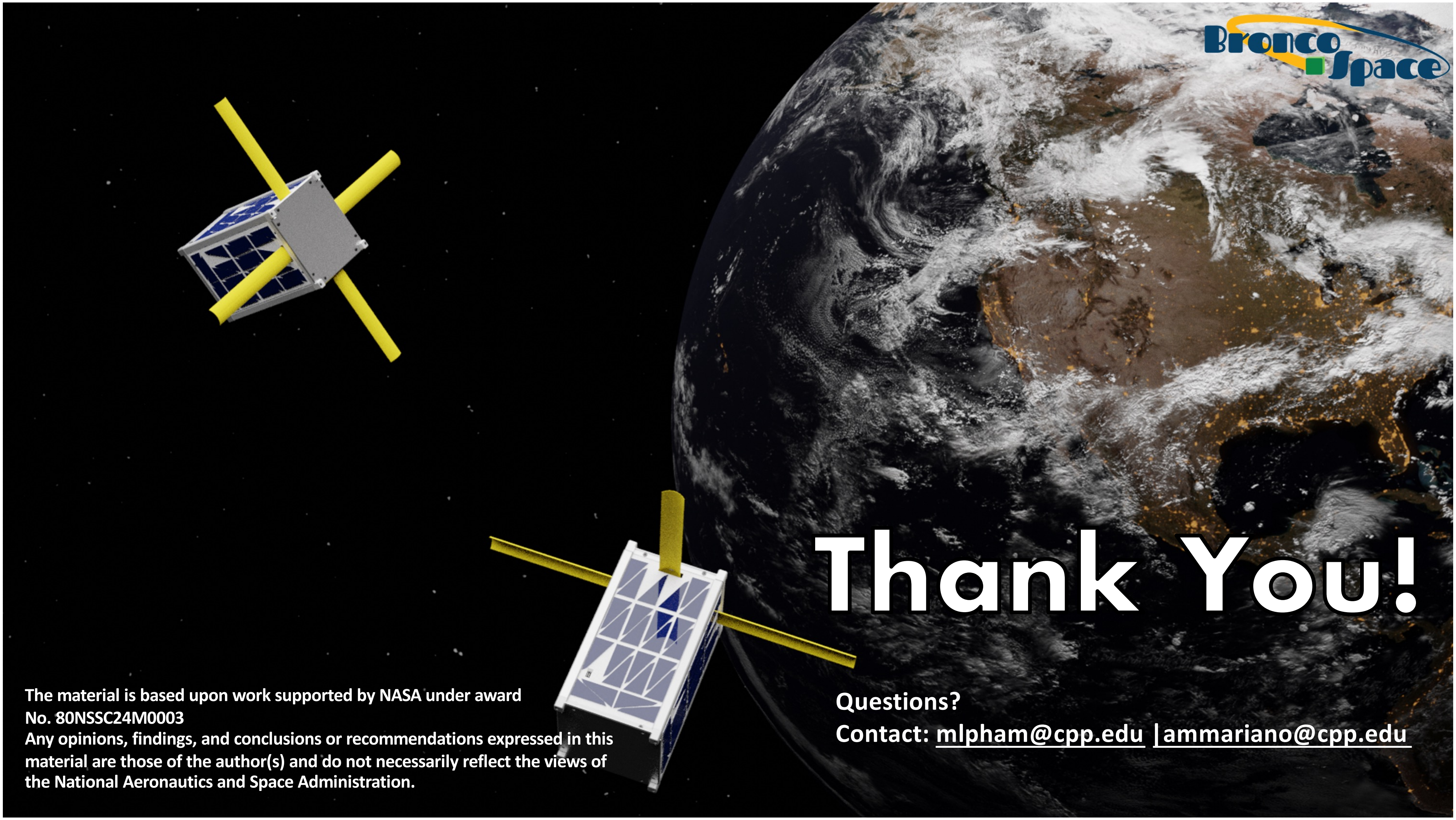
- Usually, our software manifests as a set of state machines.
- Software becomes mission-specific and unscalable.

- Need for a reusable and scalable software framework to save time on redeployment of core functionalities between spacecraft.
  - Downlink, telemetry, health monitoring, commands, etc.
  - Mission-specific components should be able to comfortably connect to existing trusted, robust, and generalized software.

Enhancements / Impacts

- Inference Time (YOLO Algorithm)
  - SoA: 4 Images/Sec
    - Using the Mars Ingenuity Helicopter Processor
  - Target: ~1,400 Images/Sec
    - Using the proposed SCALES dedicated co-processor
- Ability to directly train new ML models on board, reducing the need for ground based high performance computers and costly downlink time.
- Significantly enhance satellite productivity by enabling autonomous decision-making.
  - Cislunar and Deep space
- Enhance adaptability to dynamic environments.




Bronco Space
Thank You!
Questions?
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