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Small Satellite Research Laboratory

The Feasibility of Structure from Motion over Planetary Bodies with Small Satellite Systems

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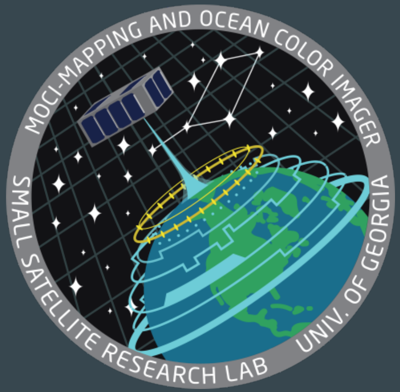
2017 CURO Syposium

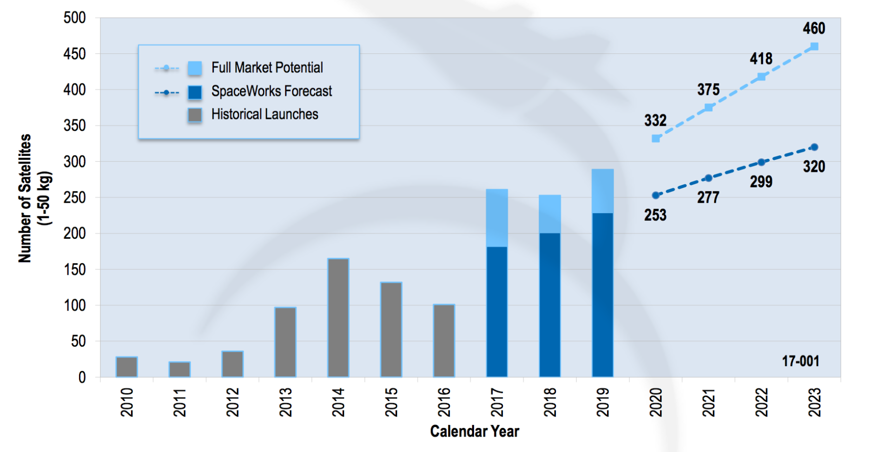
What is the UGA SSRL?

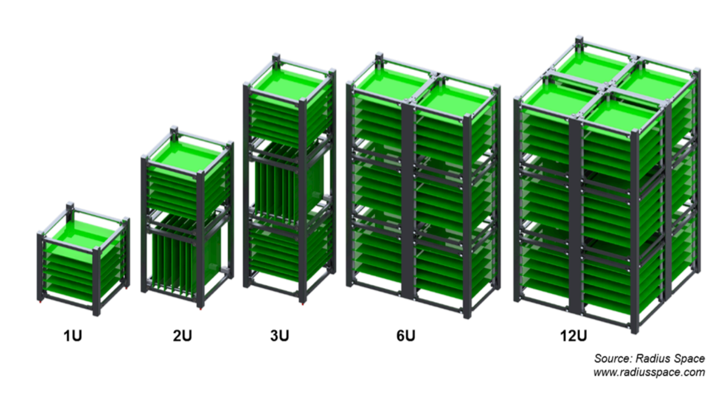
- Student Run
- Student Founded
- Faculty Supported
- NASA and UNP/AFRL funded
- 2 Cube Satellite Missions
- 54 Student Researchers



What is a Cube Satellite?

- 10cm x 10cm x 11.35cm
- 1.33 kg per Unit
- Low Cost
- MOCI and SPOC are both 3U CubeSats
- The fastest growing type of satellite in the market





Courtesy of spaceworks 2017 small satellite market forecast

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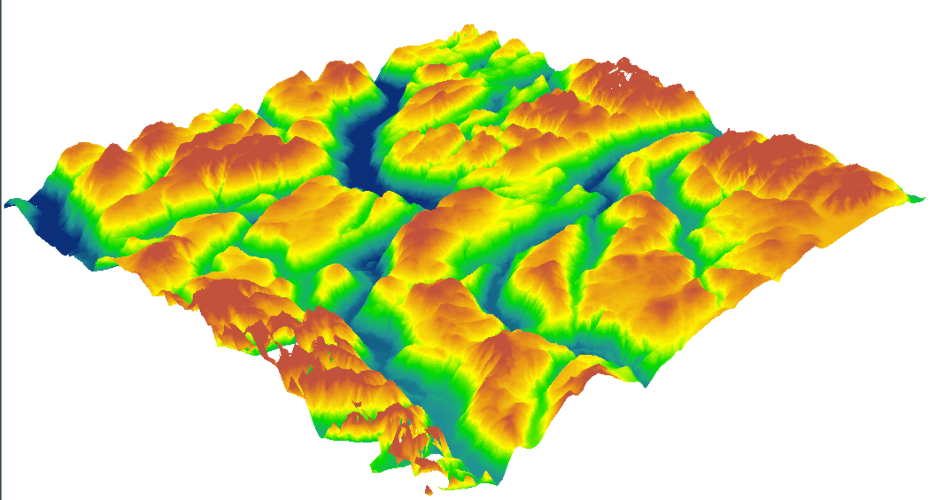
The Mapping and Ocean Color Imager Satellite

- M.O.C.I.
- Will be the first satellite dedicated to performing structure from motion of targets on a planet's surface
- End results are point clouds and surface meshes that can be used to make Digital Elevation Models



DEM, Courtesy of NASA Space Shuttle STRM payload

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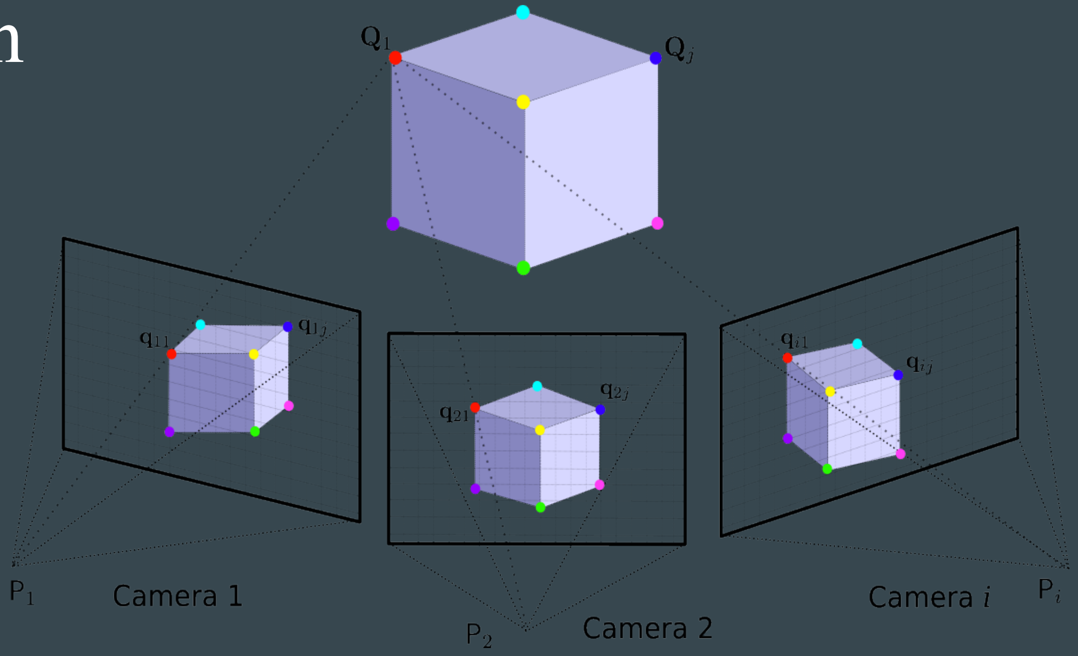
Structure from Motion

- Input is a set of 2D images, output is a 3D structure
- Generates a point cloud from multiple images from multiple angles
- Sort of like saying "cloud computing" or "Big Data", it's really just a buzz word with lots of complicated parts



Courtesy of Julien Michot

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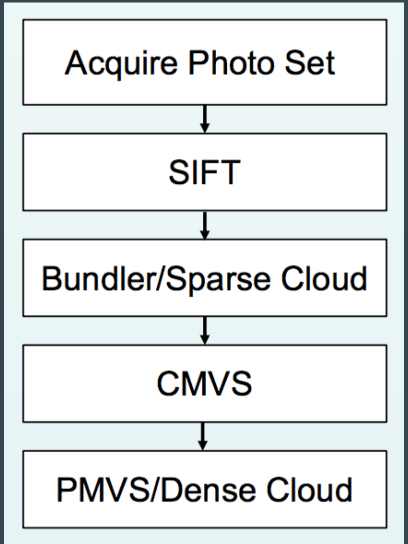
Structure from Motion … in space

- GSD/Imaging resolution issues
- Difficulty to find required image sets, so simulation
- For space a custom solution is needed – Identification and testing of custom solutions is time consuming
- Rigorous testing regiment

Table 2. Surface Normal Estimation Results

GSD (m)	Num. of Pts.	Normal	Variance (m^2)
		Surface 1	
0.25	1130	[0.011, 0.002, 1.000]	0.151
0.5	374	[0.020, 0.018, 1.000]	0.224
1.0	80	[-0.020, 0.024, 1.000]	0.407
2.0	40	[0.035, 0.072, 0.997]	0.688
		Surface 2	
0.25	793	[0.037,-0.009, 0.999]	0.146
0.5	321	[-0.033, 0.009, 0.999]	0.251
1.0	72	[-0.507, 0.013, 0.862]	0.661
2.0	20	[-0.545, 0.016, 0.838]	1.743
		Surface 3	
0.25	700	[0.001,-0.005, 1.000]	0.155
0.5	330	[0.010, 0.018, 1.000]	0.177
1.0	80	[-0.163, 0.001, 0.987]	0.712
2.0	23	[-0.262,-0.010, 0.965]	0.894

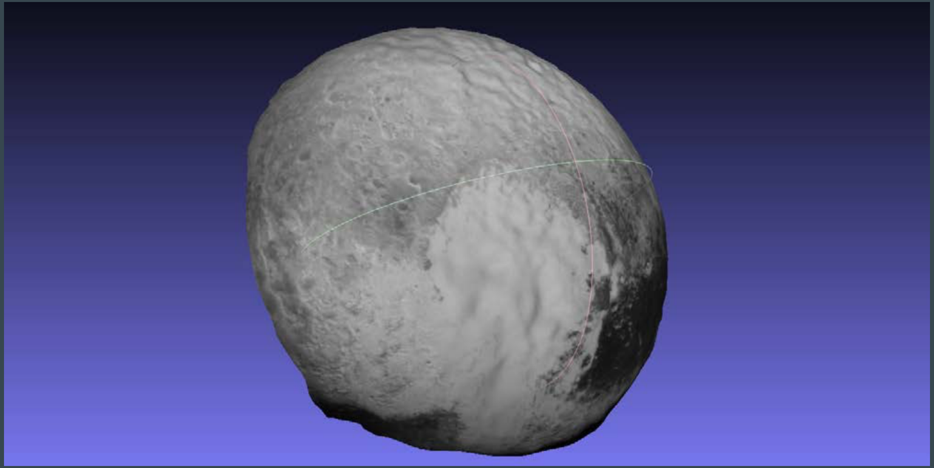
Relationship between GSD and point cloud generation, as well as surface normal detection (FOV not accounted for). Courtesy of Stoddard et all 2014.

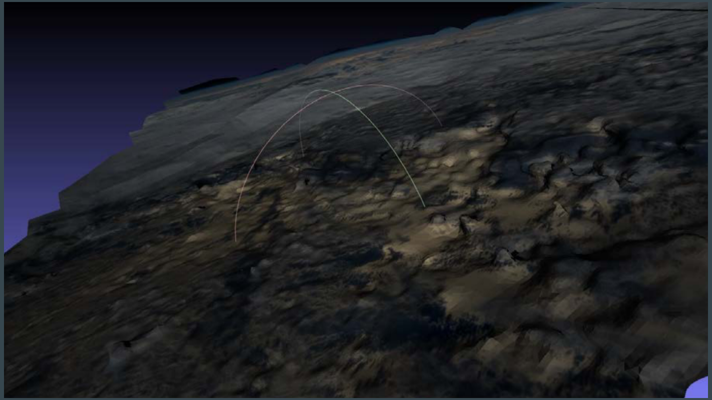


A typical terrestrial SfM workflow

Initial Testing

- SfM to Mesh Generation with ISS image data
- SfM to Mesh Generation with New Horizons image data
- Feasible for Initial DEMs of rare planetary targets
- Feasible for Cloud Elevation Modeling





SSRL generated test data

Simulating Realistic Data Acquisition

- Custom program with Blender as rendering engine
- Build a .json config file with test parameters
- Script can be automated to test multiple SfM solutions
- Procedural terrain generation for varying large test sets

```
{
    "LandscapeMesh":"landscapes/main.ply",
    "LandscapeTexture":"textures/dirt-1.jpg",
    "EarthTexture":"textures/dirt-2.jpg",
    "PhotographRange":"45d",
    "PhotographCount":"1079"
}
```

Example configuration courtesy of Jacob Conley

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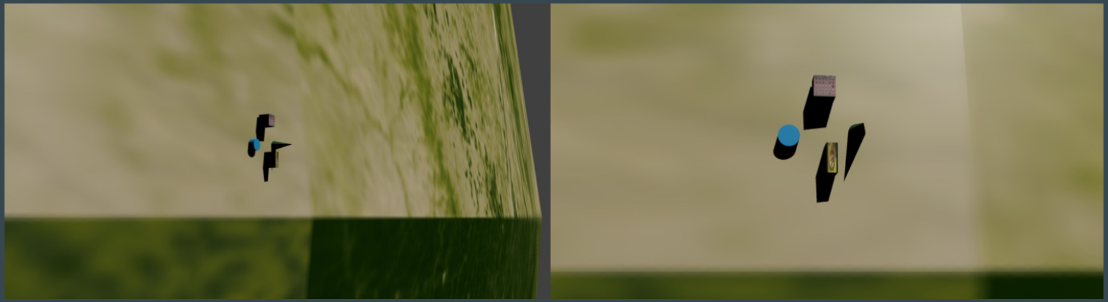
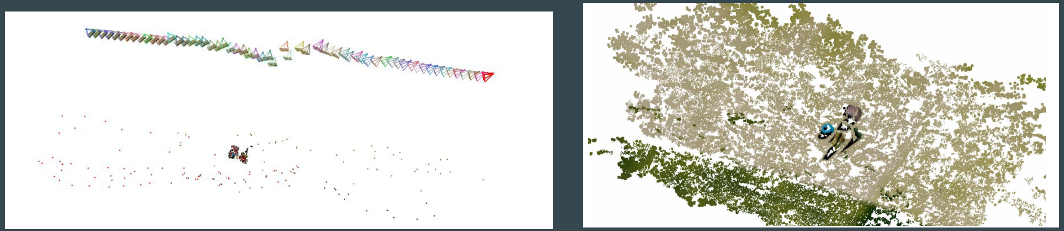
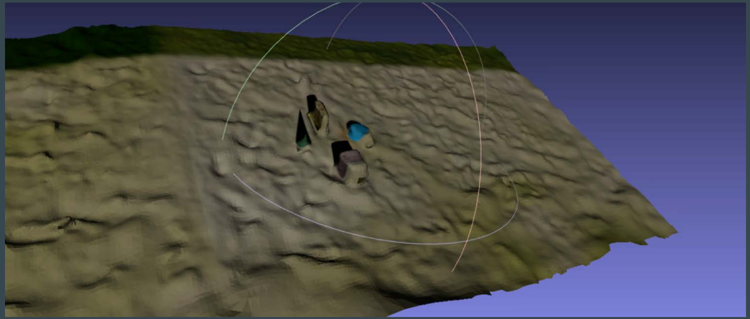
Simulating SfM

- From Data Set, Initial Tests with Standard SfM workflows
- Some manual error/noise reduction is required for good mesh data
- 30 degrees off nadir resulted in full data sets, more than 30 degrees resulting in a computation failure







SSRL generated test data

Initial Simulation Results

- Improvement from 18m GSD would be needed for finer resolution.
- With a single onboard GPU, compute time was estimated to be 3.3 hours worst case and 0.9 hours best case
- SIFT, Tie point generation, and feature detection in general are target areas for improvement/optimization

Table 2: Data sizes for the successful tests in Table 1

Test	Image Count	Image Size	Sparse Cloud	Sparse Size	Dense Cloud	Dense Size	Mesh	Mesh Size	Texture Size	Total Size
Phobos	2	1.97MB	515	67KB	1,051	8.85MB	Fail	N/A	N/A	10.9MB
Pluto Test 1	16	1.63MB	11,953	3.1MB	35,153	47.6MB	41,273	1.6MB	287KB	53.93MB
Pluto Test 2	15	1.6 MB	11,877	3.1MB	39,804	16.1MB	42,866	3.7MB	5MB	29.5MB
ISS	30	50.1MB	11,729	6.9MB	301,249	279MB	146,138	12.6MB	24.5MB	337.1MB
Test 11	100	4.14MB	30	14KB	41	277KB	Fail	N/A	N/A	4.2MB
Test 12	40	1.76MB	20	32KB	Fail	N/A	N/A	N/A	N/A	1.8MB
Test 13	100	10MB	514	542KB	79,674	39MB	66,400	5.7MB	5.2MB	60.5MB
Test 14	40	3MB	547	158KB	50,438	24.1MB	21,379	1.8MB	N/A	29.1MB
Test 15	200	11.1MB	39	150KB	Fail	N/A	N/A	N/A	N/A	11.3MB
Test 16	100	5.94MB	35	102KB	Fail	N/A	N/A	N/A	N/A	6.1MB
Test 17	80	5.33MB	241	216KB	11,203	11.5MB	Fail	N/A	N/A	17.1MB
Test 18	100	10.1MB	672	363KB	87,156	58.8MB	42,389	3.7MB	789KB	73.8MB
Test 19	80	7.9MB	670	334KB	113,508	57.9MB	49,484	1.8MB	N/A	67.9MB
Test 20	60	5.39MB	1,208	450KB	107,852	47.8MB	45,312	3.9MB	667KB	58.3MB
Test 21	40	3.06MB	329	108KB	20,204	15.3MB	16,717	612KB	7KB	19.1MB
Test 22	32	2.38MB	34	60KB	4,956	3.86MB	Fail	N/A	N/A	6.3MB

(4612/325) * (60) * (14) = ~11,920.25 seconds, or 198 minutes or 3.3 hours

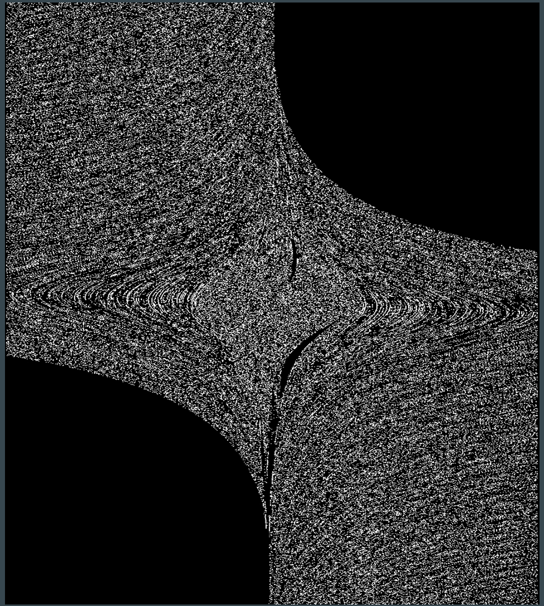
(4612/325) * (60) * (4) = ~3,405.78 seconds or 57 minutes or 0.9 hours

SSRL generated test data

*Uses eSOM TK1 and not Jetson TX1 or TX2, TX models operate around 14 minutes

Optimization and Customization of SfM

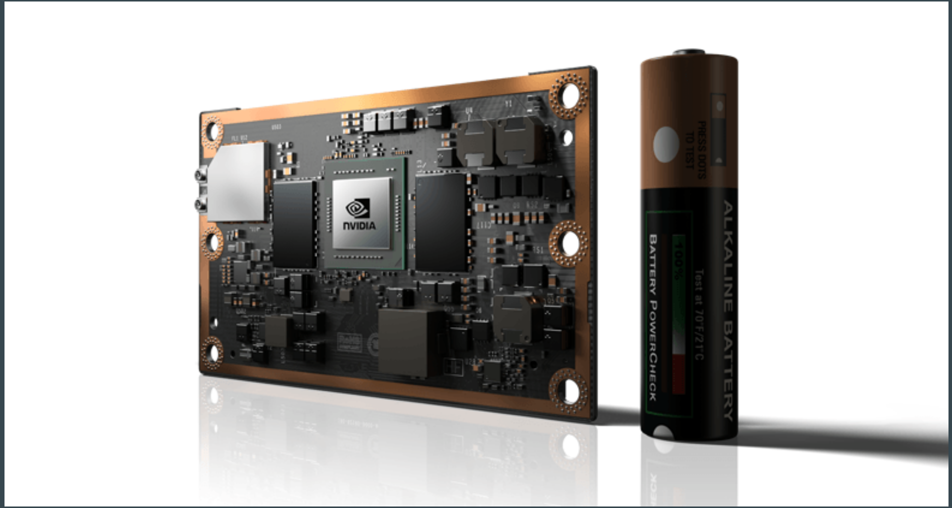
- Custom tie point detection, Custom Feature detection
- Features from accelerated segment test (FAST) can help enhance SIFT for our case
- FAST feature detection is used to find key-points over the set of images. Images are cut into "slices" of 1 pixel in height. They are then reassembled such that the y axis represents time elapsed as the camera moves, i.e. the first row of pixel in the reassembled images is the first row of pixels of the first image, the second row is the first row of pixels of the second image and so on.



Custom FAST implementation with simulated data, courtesy of Josh O'sheilds and Hollis Neel, SSRL.

Hardware Optimization

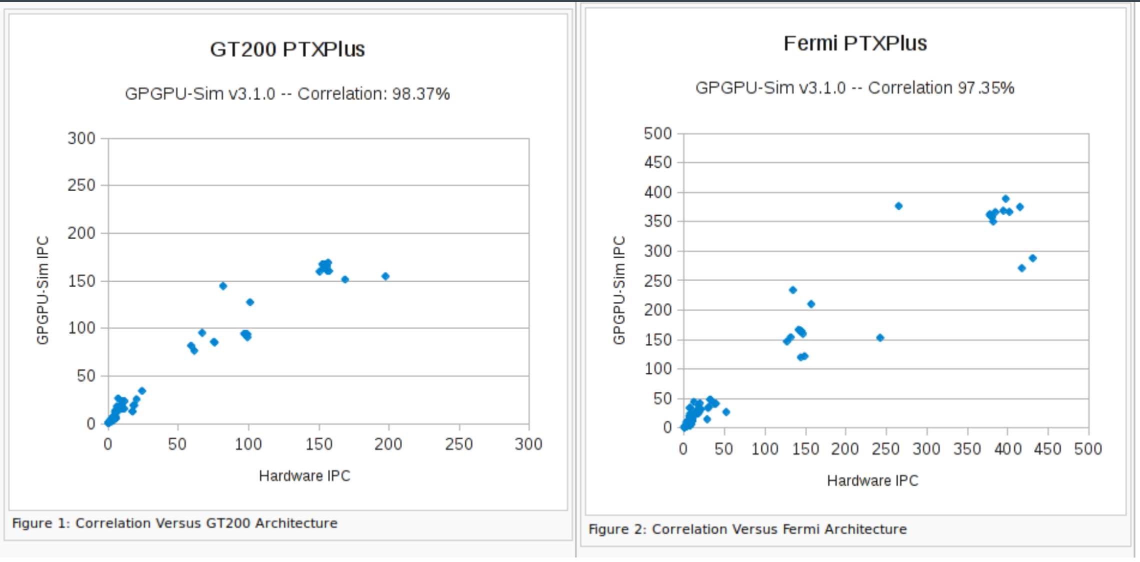
- FPGA implementation of SIFT could cut worst cast compute time by 2x or more
- Optical data moved to 10bit for faster bus transmission times
- NVIDIA GPU+CPU board as primary payload computer. Can integrate with an FPGA



NVIDIA Jetson TX2

GPU Simulations for CUDA optimization

- GPGPU-Sim, an open source NVIDIA GPU simulator
- CUDA library custom evaluation program is also an option



GPGPU architecture correlations

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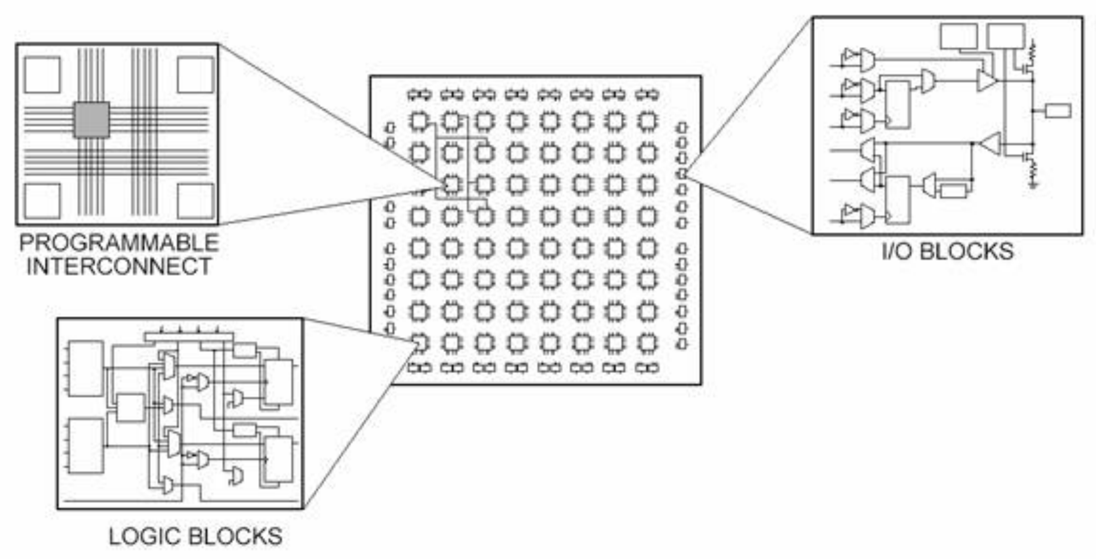
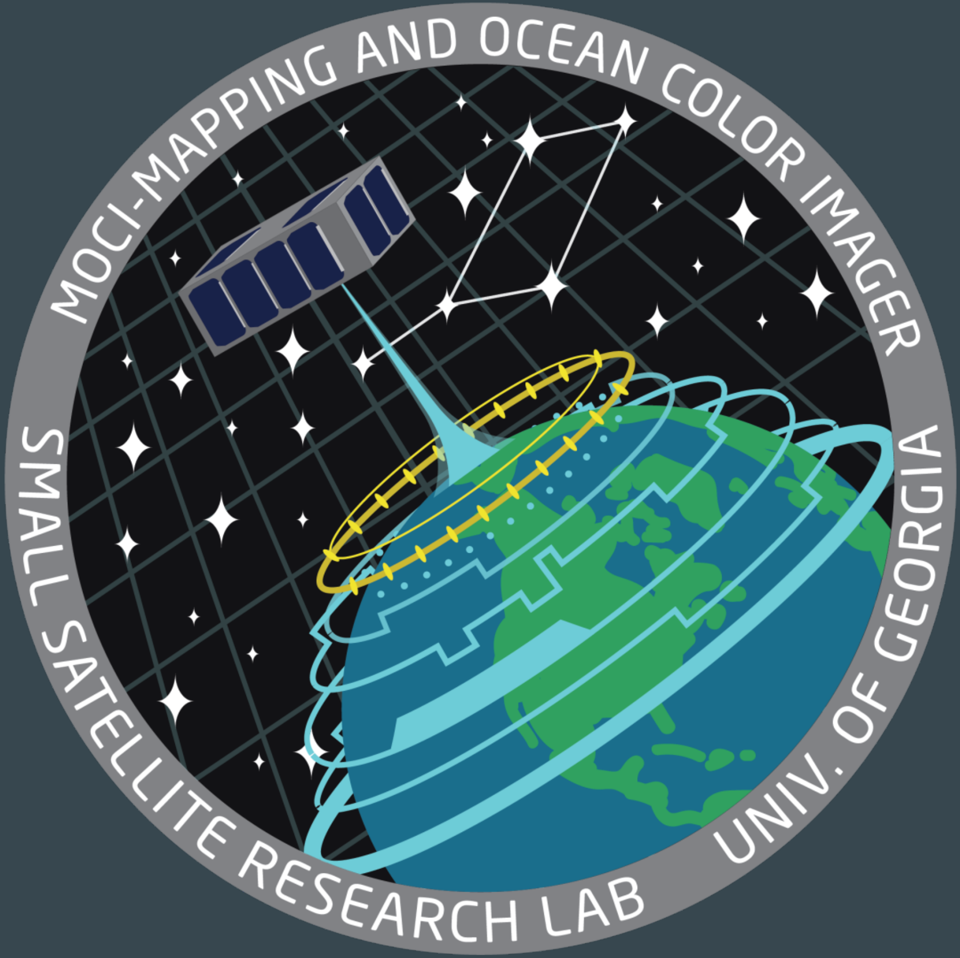
Future Plans

- Completion of custom SIFT implementation. Moving this to an FPGA
- Finalization and Automation of testing programs
- GPU finalization based on best time simulations



Example FPGA

Questions?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