Intelligent Small Satellite Swarm Control for Avoiding in Space Debris

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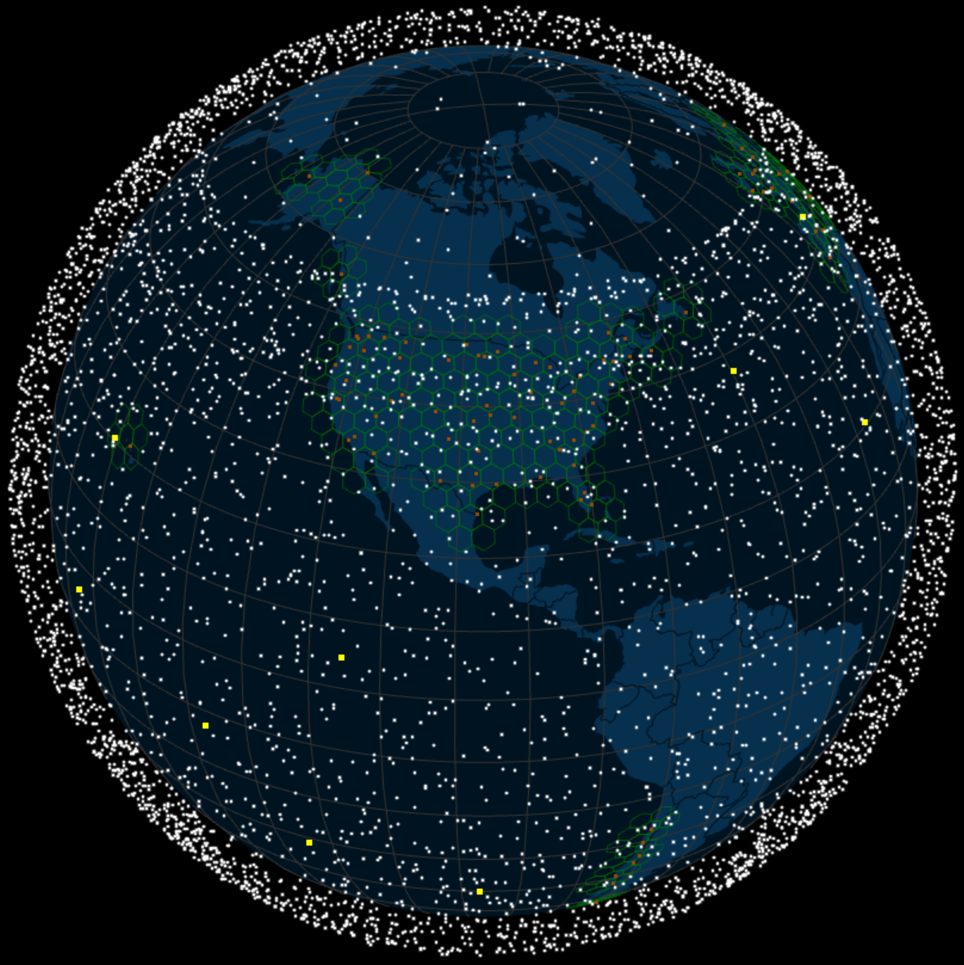
Stottler Henke Associates, Inc.

Large SmallSat Swarms



SpaceX Starlink

Amazon OneWeb

Landsat Satellites

- The Landsat satellites have constraints based on a need to image the entire Earth every 16 days.

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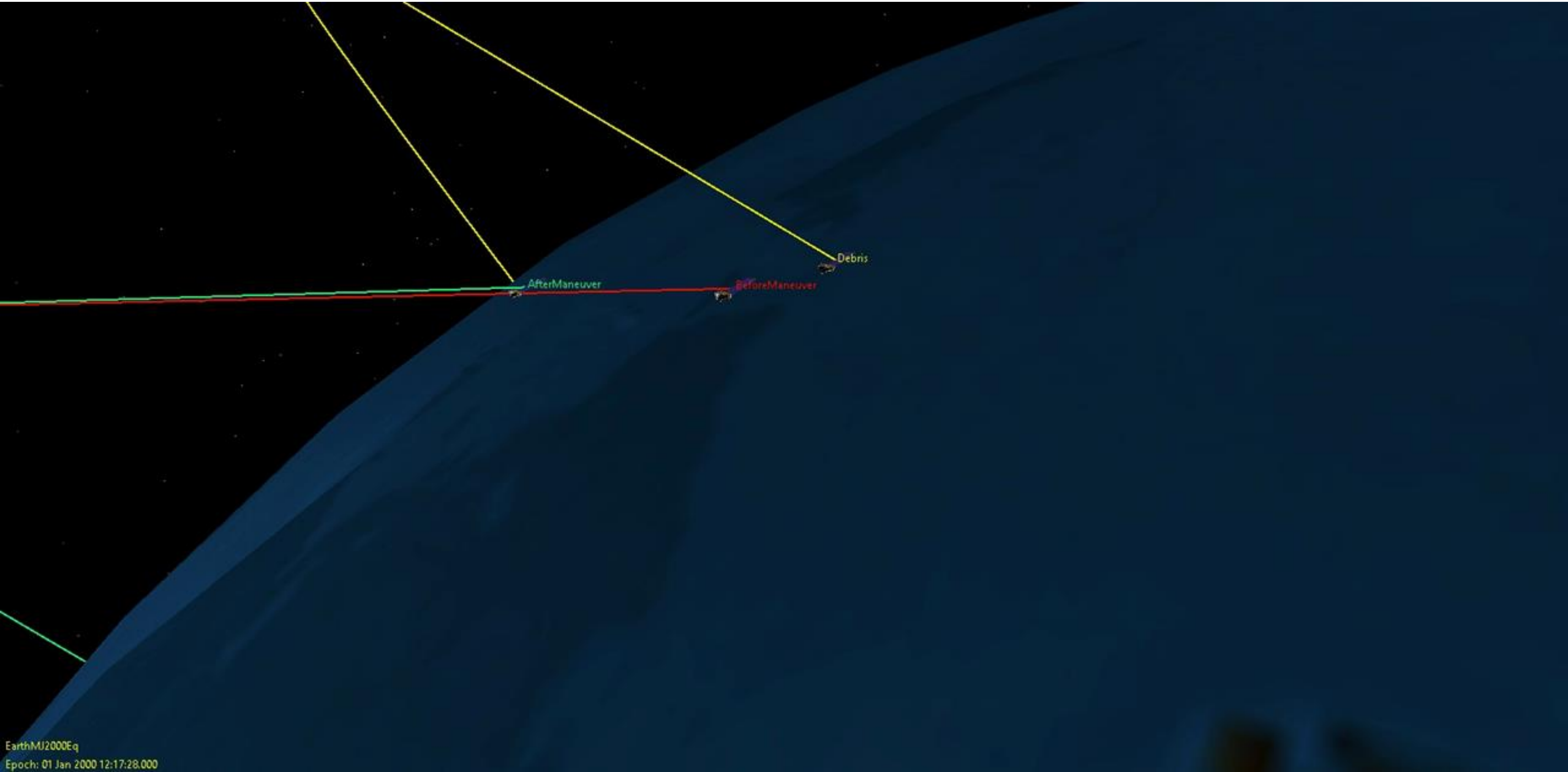
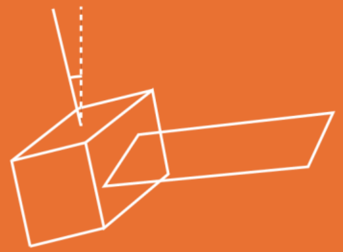
Scenarios

1. No Maneuver
2. Orbit Raising
3. Orbit Lowering
4. Landsat with Orbit Coordination
5. Trailing Satellites
6. Massive Internet Provider with No Constraints
7. Massive Internet Provider with Attitude Constraints
8. Massive Internet Provider with Temporal Constraint

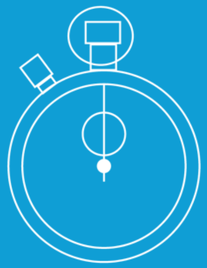
Scenario Visualization: Basic Orbit Raising



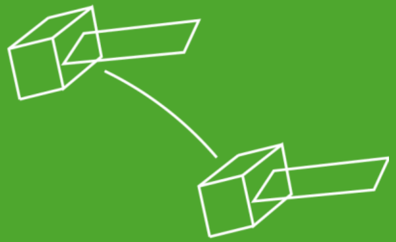
Mission Constraints



Attitude constraint, e.g. keep a phased array antenna pointed at the ground

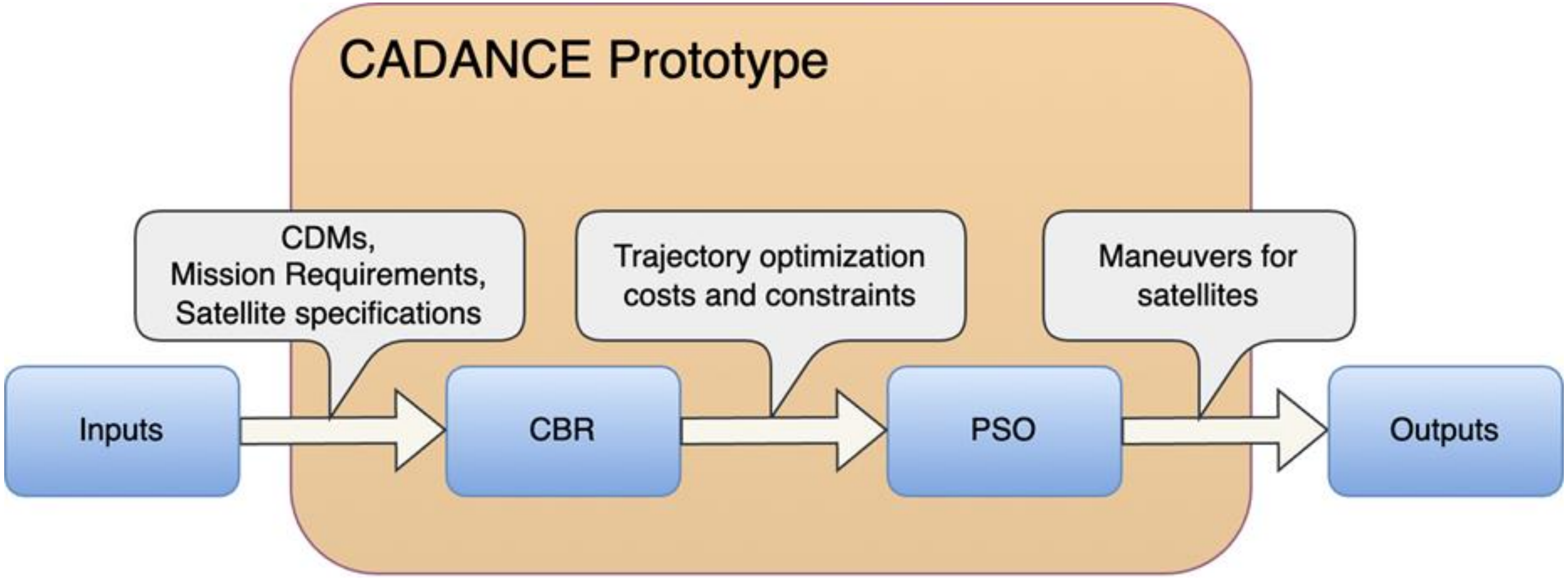


Temporal constraint, for avoiding performing a maneuver when a mission task needs to be done

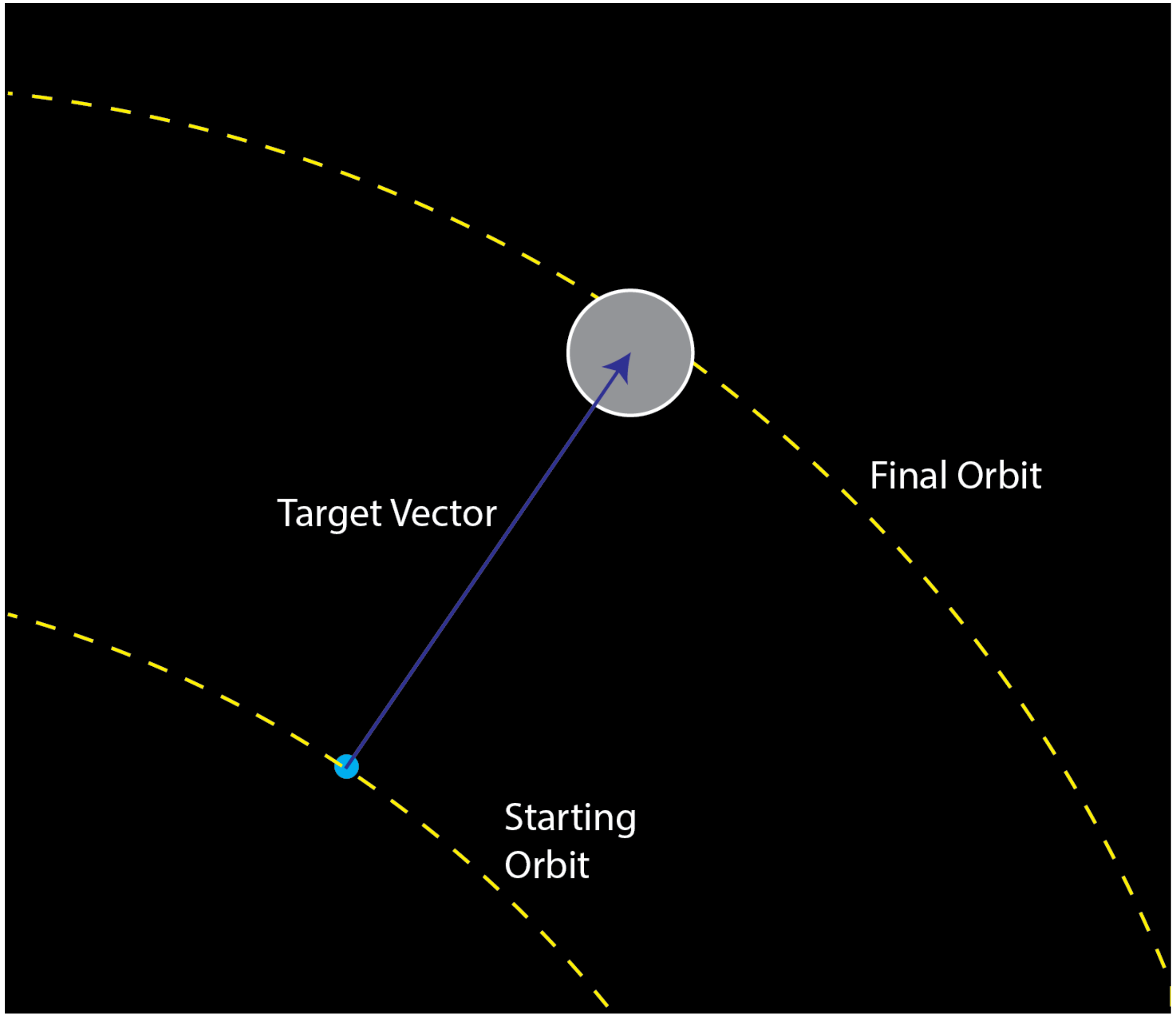


Relative motion constraint, when satellites need to maintain a certain distance between them

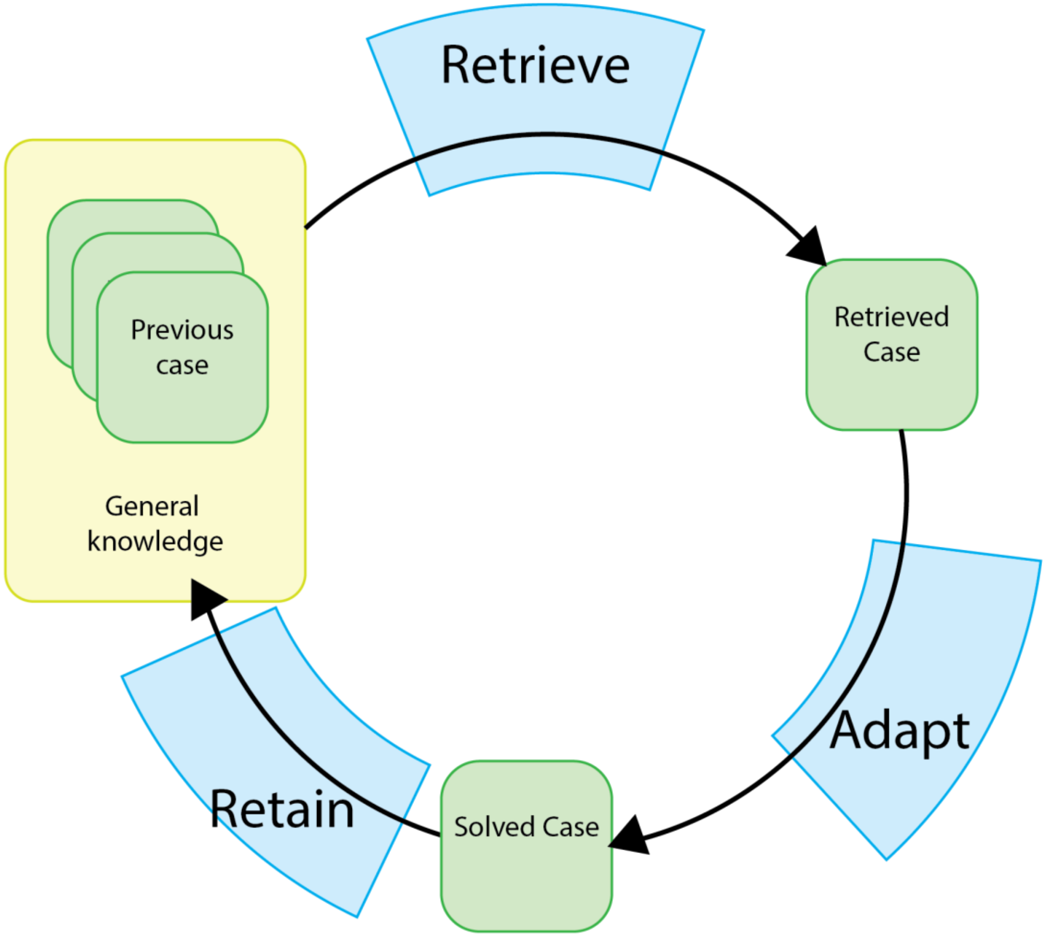
CADANCE (Coordinated Debris Avoidance) Architecture



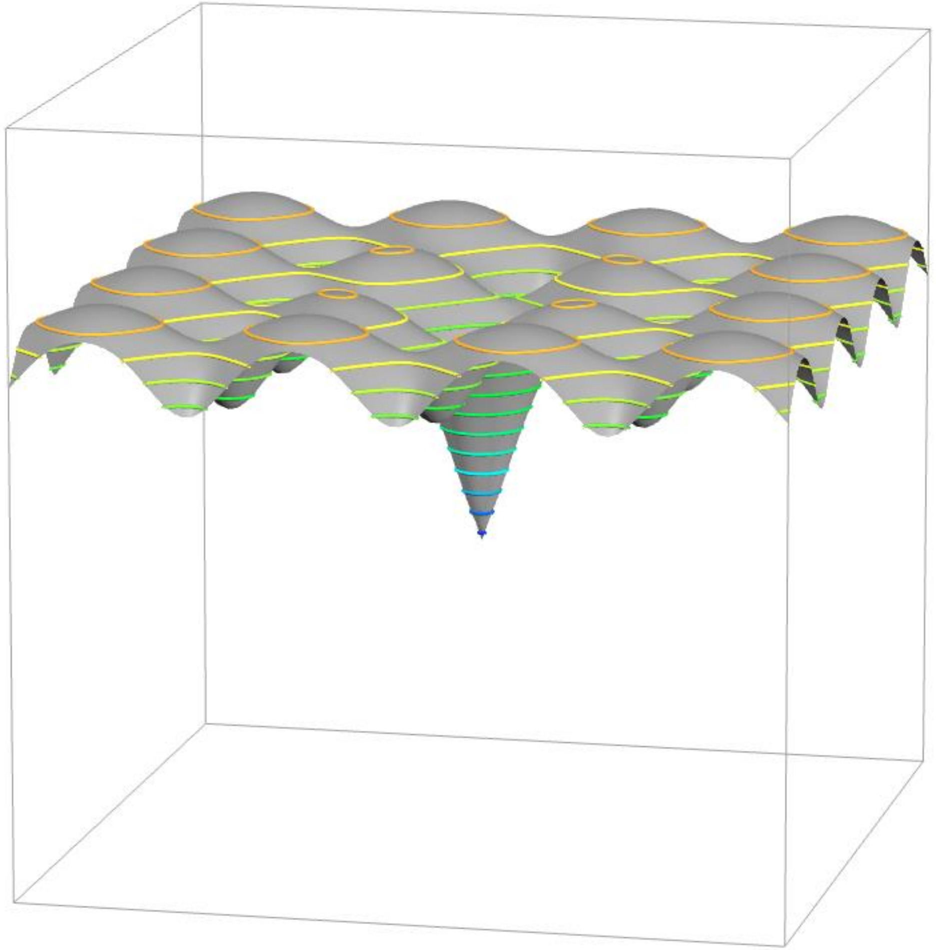
Geometric Constraints for Orbit Raising

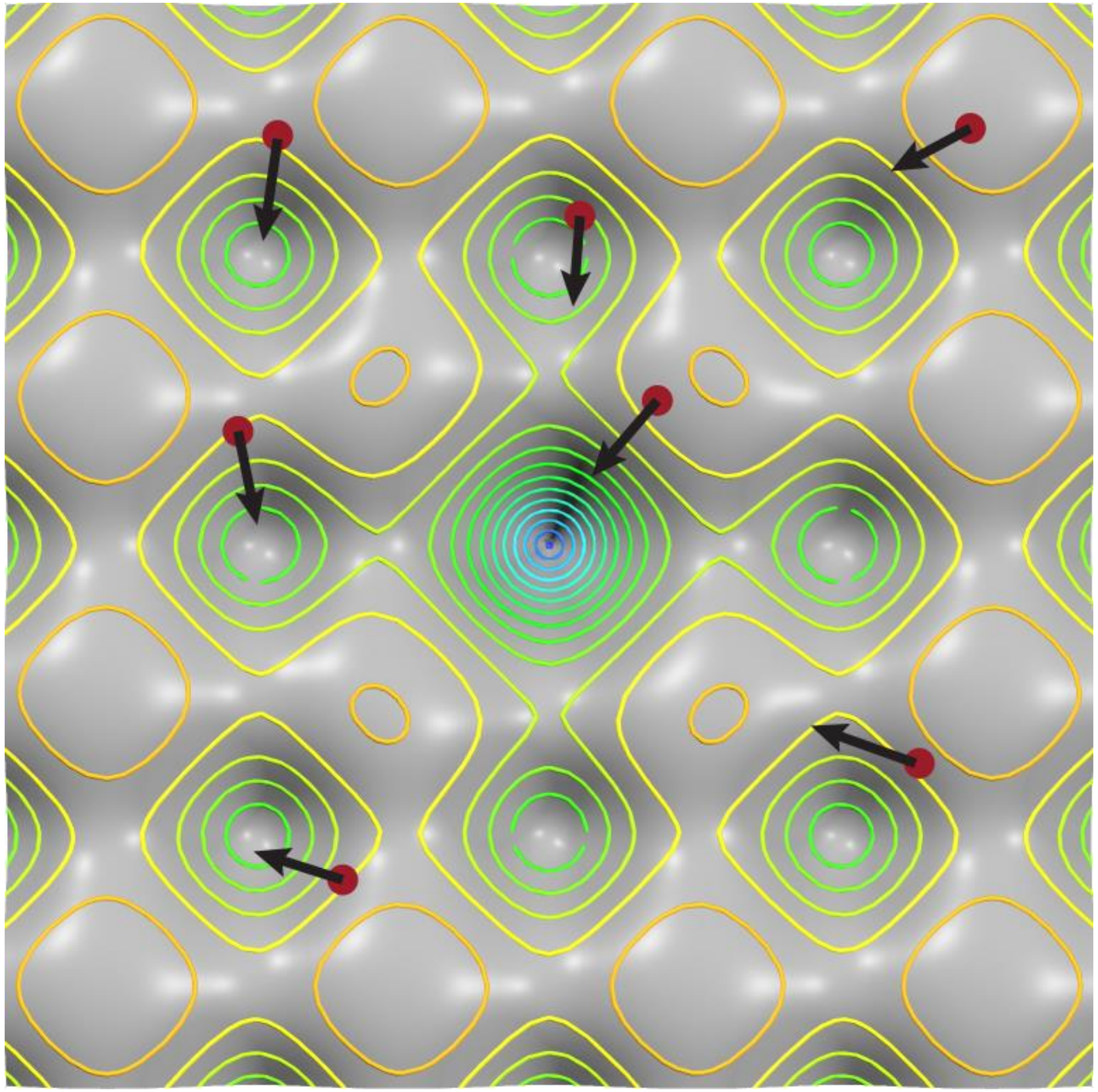


Case-Based Reasoning

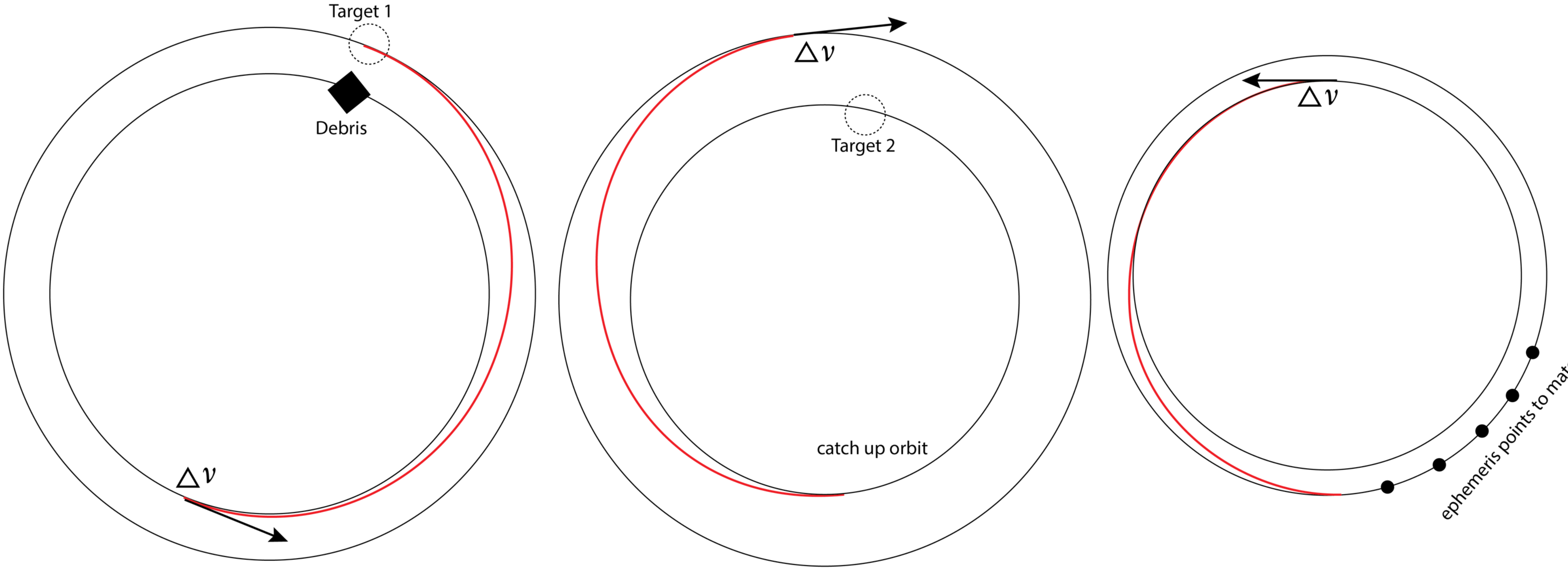


Trajectory Optimization with Particle Swarm Optimization





Orbit Raise and Restore Example



Scenario Runtimes

Scenario	Runtime (s)
No Maneuver	N/A
Orbit Raising	39.265624
Orbit Lowering	116.021613
Landsat with Orbit Coordination	51.123566799
Trailing Satellites	86.410465695
Massive Internet Provider with No Constraints	141.489585273
Massive Internet Provider with Attitude Constraints	58.386330
Massive Internet Provider with Temporal Constraint	19.366113243

Final Trajectories

- The acceptable threshold for P_c for all constellations is 1E-6

Scenario	No Maneuver		Maneuver	
	Distance (m)	P_c	Distance(m)	P_c
No Maneuver	398.529	1.464E-11	N/A	N/A
Orbit Raising	348.713	7.947E-6	1574.000	5.240E-7
Orbit Lowering	87.420	9.414E-4	5127.089	6.315E-7
Landsat with Orbit Coordination	249.967	7.607E-5	2967.424	5.070E-7
Trailing Satellites	350.520	9.609E-6	1996.000	5.321E-7
Massive Internet Provider with No Constraints	279.362	2.620E-5	12011.452	6.235E-7
Massive Internet Provider with Attitude Constraints	314.038	3.142E-5	7912.969	9.481E-7
Massive Internet Provider with Temporal Constraint	210.012	9.663E-5	9690.403	8.573E-7

Advantages

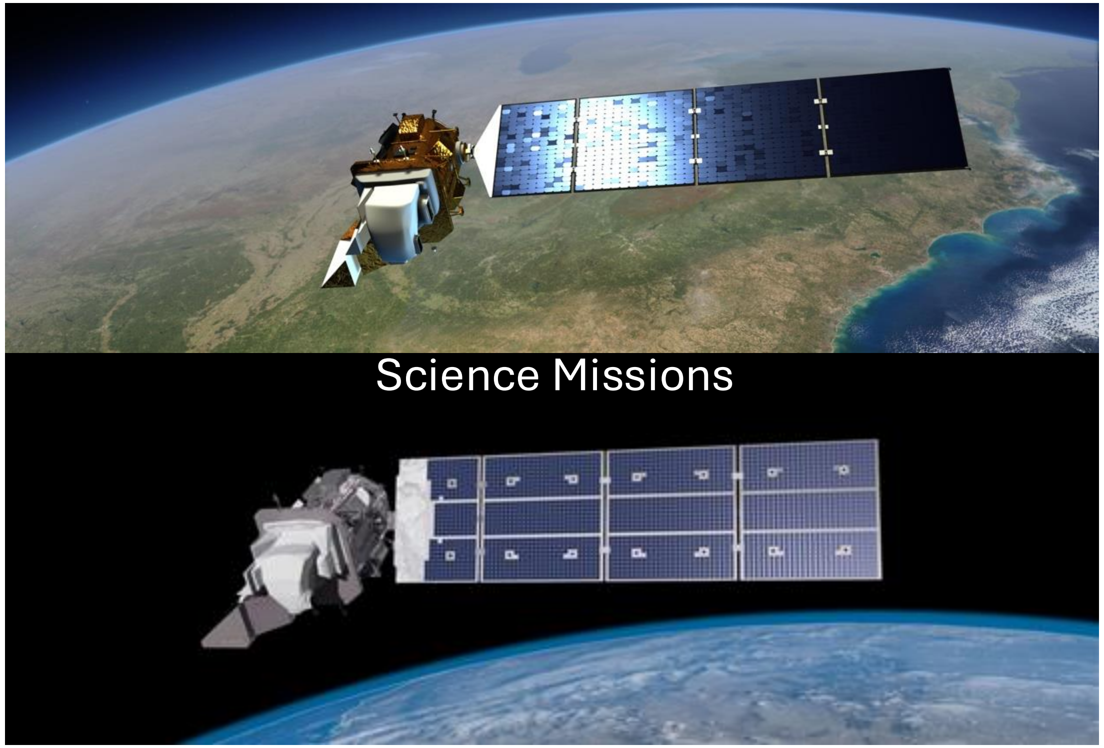
- Fuel efficiency can be easily included in the optimization process
- Can add safety constraints
- Computationally efficient

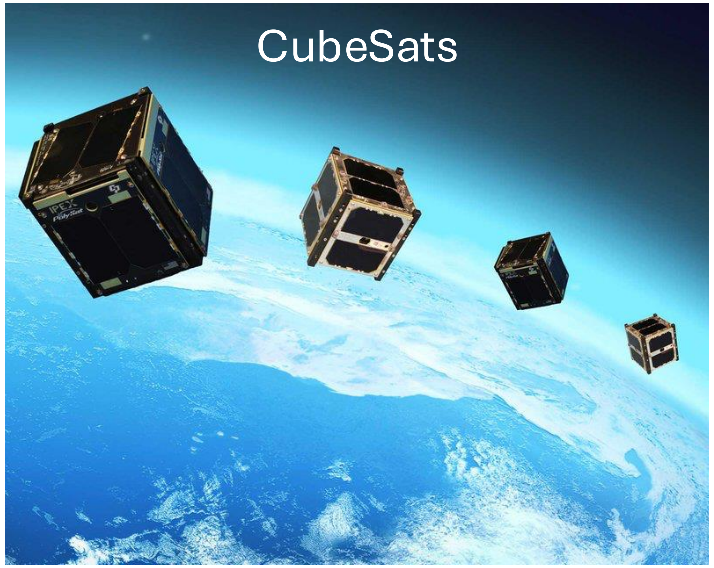
Disadvantages

- Optimization is not guaranteed to find a feasible solution (might need to be re-run)

Applications


Satellite Internet Providers


Science Missions


CubeSats

Future Work

- Test CADANCE against real, not simulated, conjunction avoidance scenarios
- Replace centralized controller with a distributed algorithm
- Implement version that can be integrated into a flight framework, and run on a flight computer

Summary

- CADANCE can reduce the probability of collision to below a required threshold for a variety of different satellite swarms
- CADANCE uses constrained optimization as a shared representation between high-level planner and trajectory optimizer to create an end-to-end approach
- CADANCE is efficient (<142 seconds to plan multi-maneuver trajectories)

Questions?

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