Universiteit van Amsterdam

Project Plan

N-Body Simulation Integrating Atmospheric and Orbital Dynamics for Optimizing Spacecraft Launch Trajectories

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Group:
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Course:
Project Computational Science

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Scientific question

With the increasing number of satellites launched annually, Earth's orbit faces congestion, raising the risk of potential collisions during spacecraft launches. Accurate predictions of trajectories of these satellites are important for ensuring safe navigation through Earth's orbit and beyond. This project investigates the computational challenges of predicting temporary satellite-free zones and optimal spacecraft trajectories.

The study simulates a hypothetical mission to Jupiter, focusing on the movement of satellites around Earth and the paths of planets in the solar system. It also aims to find the best and safest route for the spacecraft, using as little fuel as possible and avoiding collisions. The key phenomena modeled include gravitational forces from Earth and other celestial bodies, atmospheric resistance, and potential energy savings through gravitational assistance.

Research Questions

1. How can we predict the timing and location of a temporary satellite-free zone with a comfortably large radius above the launch site, based on n-body simulations of the solar system and man-made satellites, to optimize the safety of spacecraft launches?

2. Given a fixed amount of fuel, what is the optimal trajectory for a spacecraft to travel from the launch location to Jupiter, possibly utilizing gravitational assist maneuvers while navigating through the satellite-free zone previously found above the launch location.

Hypotheses

1. The timing and location of these zones can be accurately predicted by N-body simulations accounting for gravitational and atmospheric interactions between the solar system and man-made satellites.
2. The model will be accurate enough to be able to do long distance path searches between the two destinations.

This research advances computational science by modeling the interplay between natural celestial mechanics and human-made orbital systems, offering critical insights for modern space exploration.

Numerical method

The project intends to combine the Fast Multipole Method with a Barnes-Hut approach. The idea being to use FMM for the dynamics near Earth and the Barnes-Hut method for the larger scale interactions. They are similar in that they both rely on hierarchical partitioning of space and make use of an octree making them compatible for implementation. Furthermore the project intends to use a Gauss-Legendre integrator for it's accuracy and long-term stability and energy conservation. We intend to validate the data in the simulation by comparing with real-world observations (NASA, TLE, etc).

Provisioned tools

The project will make use of Python as its primary programming language due to it's familiarity among the team members and it's broad scientific libraries of which the following will be used:

- NumPy and SciPy for numerical computations and their handling of large datasets.
- Matplotlib and Plotly for their 2D and 3D data representation.
- Cython or raw C/C++ for high performance components if necessary.

Finally the project plans to use Git for version control and Discord / Whatsapp alongside in person meetings as means of communication.

Plan for division of work

1. **Git Repository Setup, Data Collection and Pre-processing:**
   - All members will collaboratively set up the GitHub repository, establish branching strategies, and define coding standards.
   - All members will gather satellite positional data from NORAD's TLE and other relevant databases.
   - Collaboratively develop scripts for data cleaning, pre-processing, and storage.
2. **Simulation:**
   - Jointly implement the N-body simulation framework.
3. **Statistical Analysis:**
   - Collaboratively perform statistical analyses on the collected data.

4. **Visualization:**
    - All members will contribute to creating visualization tools using Matplotlib and Plotly.
    - Develop interactive plots within the Jupyter notebook together.
5. **Performance Optimization:**
    - Jointly identify performance bottlenecks and optimize the code using Cython where necessary.
    - Conduct performance testing together.
6. **Documentation and Reporting:**
    - All members will collaboratively write the project reports.
7. **Poster Preparation:**
    - All members will contribute to designing and creating the project poster.
    - Allocate tasks such as content creation, graphic design, and layout management.

Timeline

Week 1	• Set up GitHub repository, establish branching strategies, and define coding standards. • Make sure each team member understand the methods and tools used for this project (Fast Multipole Method, Gauss-Legendre etc.) • Data collection from NORAD's TLE and other sources. • Complete data pre-processing.
Week 2	• Start implementing the N-body simulation framework. • Integrate Fast Multipole Method and Barnes-Hut into simulations. • Begin statistical analysis for satellite movements. • Develop basic visualization.
Week 3	• Conduct comprehensive statistical analyses (time-series and correlation studies). • Interactive plots in Jupyter notebooks. • Optimize simulation code for performance. • Validate simulation results with statistical data analysis. • Finalize data visualizations.
Week 4	• Conduct final testing to ensure reproducibility of results. • Complete the project report. • Design and finalize the project poster.