Georgia Institute of Technology

School of Physics

Progress Report

PHYS 3266

Simulating Orbital Perturbations and Inferring their Sources

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1 Research Topic & Question

Subfield: Astrophysics (Celestial Mechanics)
Question: Given a deviation from a planetary Keplerian orbital trajectory, can we determine properties of an intervening planet?
The goal of our project is to create a computational simulation of a method that was used to predict the location and properties of undiscovered planets - which ultimatley led to the predictions and discovieries and Neptune and Pluto, and continues to create wonder about more potential planets in the Solar System. Our goal is to take in data on the orbits of a set of planets and use and N-body simulator to guess where a planet would need to be to create observed orbital perturbations.
Repo: https://github.com/jbrandt35/CompPhysicsProject

2 Current Setup

For our N-body simulator, we decided to implement the Verlet Method, inspired by one of the homework problems (described more in 4).

For initial conditions, our current implementation uses JSON files. Each planet/star has a JSON file with information about its initial position and velocity in the solar system with respect to the Sun. This data is taken off of Wikipedia. We are currently working to use an ephemeris from Astropy to get more accurate and specific initial conditions.

Through our testing, we are getting satisfactory results in very small time-domain runtimes. We can complete multiple Earth orbits with a time-step of one hour in only 10 seconds on our laptops. We plan to run our code on PACE, and are excited to see the performance we will be able to achieve.

3 Current Status

We currently have a full solar system N-Body Simulator model, which gives stable orbits for all the planets in solar system, and outputs arrays upon which we can perform various analysis to find astronomical quantities of interest. We have also built functionality in the program that calculates the eccentricity, semi-major axis and orientation of a planetary body given the position history array that our program ouputs for every body. We have code that takes this output and calculates all these orbital properties by fitting an ellipse to the orbit using the method of least squares. We are beggining to get ready to test whether our analysis will be able to pick up on orbital perterbations we plan to recreate/test, such as those of Uranus. Then we will begin to develop the process to build the functionality to predict the attributes of the planets causing the perterbations, in a similair manner to how several planets were initially discovered.

4 Difficulties

We began our project by creating a very elementary N-body simulator which simply calculated acceleration and mulitplied by a time step over and over. At the very beggining, the Earth was crashing into the Sun. Then we got it to orbit, but slowly spiral away. We fixed these problems by using the Verlet method, and are now achieving great results. An additional diffuculty we ran into was that initializing all planets at perihilion all along the x-axis caused Mercury to be slung out of its orbit, which made us realize that manually initializing position and velocity for every body in such an arbitrary manner would introduce effects that did not mirror the behavior of the actual solar system, so we altered the code to pull position and velocity initial values from Astropy's Ephemeris module, which has since produced a more accurate representation of the solar system. While this solved one of our problems, it does present a problem we are currently working on, namely that to calculate orbital properties of each body, we fit the three dimensional orbit to an ellipse, which is more difficult using the Astropy Ephemeris coordinates, which uses the barycentric center of the solar system as its reference frame. So, we are looking into implementing JPL's Horizon API which can give the Ephemeris data with respect to the ecliptic plane.

5 Figures

- Orbital Trajectories of the Solar System planets
- Difference in orbital trajectories between our guesses of planet casuing perterbations over time
- Matches between our guesses and real values over time
- Diagnostic Plots like constant mechanical energy of the solar system over time
- Changes in guessed planetary properties over time