EECS 189 - Project S Early Deadline

Kaahan Radia **Stephen Lin** **Parker Nelson** **Eric Li**

Abstract

Our goal is to create a dataset of similar quality to the data available to Greek astronomers during their time. By connecting the ancient Ptolemic model of the universe to our modern understanding of Fourier series, we've created a dataset that, given modern machine learning methods, can be used to learn planetary motion models and moon phases. In an attempt to model the uncertainty of Greek instrumentation, we've introduced noise to many of our "measurements," and taken the data from geographical regions similar to where the Greeks were.

Source code can be found here: `https://github.com/pnelson6679/projectS_early_deadline_teamSKEP`

1 Introduction

Astronomy is one of the earliest explorations of the natural world and, as such, is the foundation for modern scientific thought. The ancient Greeks, despite being false in their geocentric model, were able to make incredibly accurate predictions regarding the movement of celestial bodies in the night sky. With the recent advancements in computing power and machine learning, it is now possible to find the true fourier features that Ptolemy estimated in his model of planetary motion. The aim is to provide data which emulates ancient Greek astronomers' limited observations to show that extremely accurate predictions can still be made with a completely wrong model of the solar system.

All of the coordinates described in the data set are relative to the Medicina Radio Observatory in Italy. We chose Medicina because it was the closest to Greece in the packages we used. Each row is indexed by a timestamp and each column is a body's coordinates. The generated data starts in 1850 and goes until 2000 with a step of every 5 days. Again, due to the limitations of the package, the margin of error for choosing a time period when the Greeks were around would be too large to provide an accurate representation of planetary motion. The planets included are the five planets observed by the Greeks: Mercury, Venus, Mars, Jupiter, and Saturn. The phase angles of the moon are also included for each timestamp. Adding the angle, as opposed to the categorical phase, made the most sense for our data set because of the specificity of our coordinates in relation to time. Although the Greeks wouldn't have had access to the phase angle, they would have been able to see the phase which is essentially the same thing as the phase angle as it corresponds directly with the categorical phase. Gaussian noise has been added to all of the data to account for the inaccuracies of using tools such as the astrolabe as opposed to more accurate modern techniques.

Through the lens of the ancient Greek astronomer, we hope this brings light to how Ptolemy's model was so accurate in its predictions of planets in the night sky.

2 Methods

2.1 Planetary Motion

As mentioned in earlier sections, for our planetary position dataset we took inspiration from the Ptolemic interpretation of the solar system; this includes the particulars of the coordinate system he used (i.e. the raw data) as well as the fundamental conceptualization of planetary movements (i.e. the featurizations).

The coordinate system that many ancient astronomers used was the **geocentric ecliptic** coordinate system. This coordinate system specifies the position of planets (and local stars) relative to two quantities:

1. the ecliptic – this is the plane of Earth's orbit around the sun or in the geocentric case, the Suns orbit around the Earth.

2. the primary direction – this is the direction that is the "start" angle; convention is to use the direction from the Earth to the Sun at the vernal equinox (with some nuance to account for procession) and all angles follow given the right-hand convention.

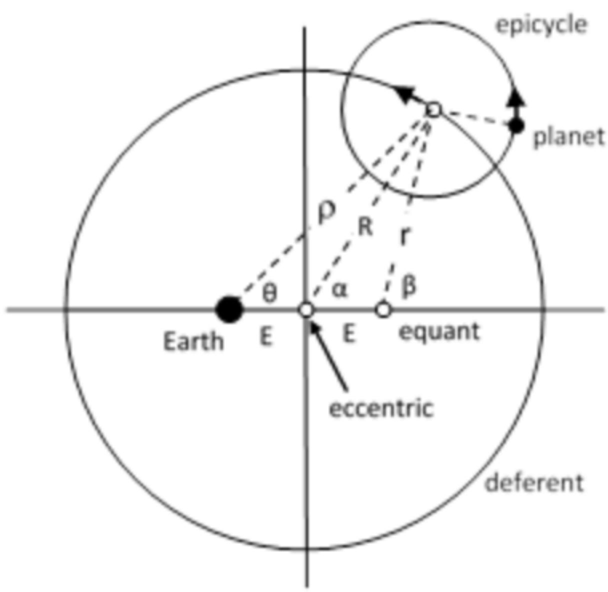
Given the plane and the direction, we can specify each planets relative position using 3 parameters:

1. the ecliptic longitude λ – this is the angle between the primary direction and the planetary object (i.e. the "horizontal" angle)

2. the ecliptic latitude β – this measures the angle from the planetary body to the ecliptic (positive towards the north and negative towards the south)

3. the distance Δ – the direct distance to the planetary body (units dependent on use case)

Now given planetary positions in this format, we can collect a ton of raw data using a library called **Astropy**. The library allows to generate the geocentric ecliptical coordinates for any planetary body at any point in time; as detailed in an earlier section we collected for the last 170 years (from 1850 till today). The details of this generation are detailed in the source code for Astropy. Now that we have our raw data, we can think about the featurization aspect of our dataset. To this we turn to Ptolemic model of the universe.



While we won't go into the weeds here, the Ptolemic conceptualization of the universe treats planetary motion as the combination of a deferent and epicycle (as pictured above). What do we notice about the movement and setup of this model? It looks exactly like a **Fourier series**! This allows us to leverage some of the concepts we've learned in class to featurize our raw data.

To put in more formally, the Fourier series perspective of Ptolemy's model states that given two **constant** angular velocities k_0 and k_1 representing the speed of the deferent and the epicycle respectively and given two coefficients a_0 and a_1 we can compute the position of the planet as:

$$z(t) = a_0 e^{ik_0 t} + a_1 e^{ik_1 t} \tag{1}$$

Notice that $k_i = \frac{2\pi}{T}$ for some period T. This implies that to solve for the planetary position, we need to find the right coefficients a_0 and a_1 for some Fourier feature with right fraction of 2π. This means that if we have enough Fourier **features**, we can approximately find these true values with certain learning algorithms.

More concretely, given a data point for planet p, we provide the raw parameters from above, but we also create the Fourier features:

$$\phi_t = \left\{ e^{2\pi i \frac{k}{N}} \right\}_{k=1}^{N}$$

Notice that the true signals exists in this conceptualization for a large enough N (i.e. fine-grained enough angular velocities), which implies that a well selected learning algorithm should be able to find the true Fourier features representing the epicycle and the deferent (given that there doesn't exist a better representation for the planet position than Ptolemy's) by setting all other coefficients to 0 and computing a_0 and a_1!

Thus we've created our data matrix for planet p, which includes for the tth time step (i.e. row): the raw features λ, β, Δ as well as the Fourier features ϕ_t. The true labels y_t is simply the position $z(t)$.

2.2 Moon Phases

AstroPy was able to generate phase angles of the moon for each time as well. The phase angle is a signed degree between 0° and 180°. The new moon, the phase where the moon is not visible, is at -180° and +180° and the full moon, when the moon is at its brightest, is at 0°. This is to account for whether each phase is waxing or waning. Accordingly, the first quarter (when the moon is waning) is at a -90° phase angle and the third quarter is at a +90° phase angle. [1]

Although the ancient Greeks did not have access to phase angles, this level of precision was what made the most sense for our dataset because we gave the positions of all the celestial bodies at a specific time. It would not make sense to give the categorical phase of the moon at that time because it would not align with the rest of our data.

3 Results

Our completed dataset has 46 columns, describing the time of each data point along with the coordinates for each planet in the geocentric ecliptic coordinate system according to the λ, β, δ as described above and the appropriate Cartesian transformation of the coordinates given by the xyz plane.

The columns for angles are given in degrees, with the exception of the moon phase, which is specified in The angles for distance are specified in astronomical units (AU), such that $1\text{AU} = 1.496 \times 10^8$km, or the average Sun-Earth distance.

We were also able to generate the appropriate phase angles for the moon at the same times for the other celestial bodies.

4 Conclusion

Through this study, we sought to act as the torchbearers of Ptolemy's legacy by providing the tools for present and future scholars to practice their understanding of the heavens through machine learning. Ptolemy's model of planetary motion serves as a bridge connecting past Greek astronomers' interpretation of the universe with present practitioners' comprehension of Fourier series. By providing this dataset, we hope to increase people's exposure to the historical context of modern astronomy. This way, we can honor the accomplishments of past scientists.

For users planning to utilize this data set, please be aware that the data has not been divided into training/validation/test/other splits of any kind. We leave split designation up to user discretion. The size is approximately 9 MB for users concerned with size.

Bibliography

[1] P. Kenneth Seidelmann. *Explanatory Supplement to the Astronomical Almanac: A Revision to the Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac*. University Science Books, 2005.

[2] Ecliptic Coordinate System. Ecliptic coordinate system — Wikipedia, the free encyclopedia, 2020. [Online; accessed 27-October-2020].

[3] Eccentrics, deferents, epicycles, and equants. `https://www.mathpages.com/home/kmath639/kmath639.htm`.