The Solar System: A Graphical Model

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Abstract

Earth is just a single planet in a large, complex system. Since the 1600s, we as a race have sought to expand our understanding of this system. How many planets are there? How is each planet different from ours, and why do these differences exist. Since the advent of space travel, research has expanded, until we know a great deal about our solar system. Yet, at the same time that our knowledge is actively expanding, the lack of viable models prevents much of this knowledge from being shared with any but the most interested.

1 Introduction

Studies have shown that even at the college level, students have minimal accurate knowledge about the solar system. It is vital that this problem be corrected at an early level by teaching elementary school children about our solar system. As the current mechanical models of the solar system are obsolete, I propose to create a model of the solar system using the technology of computer graphics in order to teach students the fundamentals of their solar system. This model will be more or less to scale, and will assist in teaching children the basics they should know about space. It will include only the nine inner planets of the solar system. Extrasolar planets, asteroids, and comets will be omitted so as not to complicate the model. When complete, students will be able to view the planets up close and study their geography. They will know the order of the planets in the solar system and will be able to obtain information about each planet's composition, size, moons, and atmosphere if they wish to do so. Most importantly, they will be able to compare the revolution periods, inclinations, and eccentricities of the planet's firsthand as they watch the planets orbiting the Sun.

Unlike many other models of the solar system, this model will be physically accurate. It will incorporate the equations of orbital physics and gravitation in order to simulate the revolutions of all nine planets. This addition will allow students to compare two planets in more ways than just size. The orbits of the planets will even be inclined to the plane of the Sun, allowing a more complex understanding than is normally sought.

The model will deal intricately with the solar system and will require quite a bit of research into the fundamental details of the sun and each of the nine planets. This research must include the distance of the planets from the Sun, the composition of the planets and their atmospheres, and details about each planet's satellites. In the same vein, this project will require knowledge of the physics of gravity and elliptical orbits. Equally important, the project will require a detailed knowledge of 3D programming in Processing.

2 Background

2.1 The Solar System

Our solar system consists of the sun and nine well known planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. An asteroid belt exists between Mars and Jupiter separating the inner planets from the outer planets. All four of the inner planets have both a solid component and an atmospheric component. They are relatively small compared to the gas giants, the four planets immediately following the asteroid belt. The gas giants are similar in that they are extremely large, have extensive atmospheres, but no known solid component, several moons, and rings. Pluto, the last planet, is extremely small and is solid, and relatively little is known about it. Each planet has its own unique axial tilt, rotation period, and revolution period. Each planet also has its own distinct orbital eccentricity and orbital inclination. All of this knowledge is basic and is important for a complete understanding of our universe.

2.2 Processing 3D Graphics

2.2.1 Lighting

A light source is required to make three dimensional graphics look three dimensional. There are three main types of light. Ambient light is light that does not come from any specific direction. Rays of ambient light have bounced so much that they light objects evenly from all sides. Ambient light does exist in our solar system because of the manner in which the Sun's light reflects from each of the planets. Directional light is light that comes from a specific direction. This light is stronger when it hits an object straight on and weaker when it hits it at an angle. After hitting a surface, the light scatters evenly in all directions. Light coming directly from the Sun is directional light. Specular light is light that bounces off the surface of an object in a preferred direction. Spot lights are also incorporated in this model, angling out from the center of the Sun in all directions in order to simulate light emanating from an object

2.2.2 Animation

Translation is the movement of an object through space. Translation is utilized in the model in order to revolve the planets around the sun. Rotation is the movement of an object around an axis and will be used to simulate the actual rotation of the planets around their axes.

2.3 Orbital Physics

All of the planets orbit the Sun in ellipses, not circles. Still, these orbits are only slightly elliptical. All of the planets orbit the Sun in the same direction and these orbits are caused by the pull of gravity between the Sun and the planet. The force between any two objects can be determined using Newton's universal law of gravitation: F = (G*m1*m2) / d2 , where m1 is the mass of one body, m2 is the mass of the other body, d is the distance between the two bodies and G is the gravitational constant. Using this law and Newton's Second Law: F=ma, the acceleration of the planet can be determined. Though acceleration due to gravity always acts in the direction of the other object, the velocity points in a direction tangent to the planet's orbit. Using these basic physical laws, I can simulate the true orbits of the planets.

2.4 Previous Work

Numerical models are software models that are used to simulate a mathematical process, and are used in many areas of study. They are vital not only in the field of astronomy, but also in such areas of research at the modeling of Earth's atmosphere. There are two main types of numerical models, statistical models and dynamic models. Statistical models use past information in order to simulate present and future occurrences. Dynamic models like the one I am building incorporate physical laws in order to track occurrences as they unfold without any reference to the past. For this reason, my model will not contain any back history of the solar system, nor will the initial positions of the planets match their current ones.

Sasha A. Barab, Michael Barnett, Kenneth E. Hay, and Thomas Keating, researchers at Indiana University, have explored the process of creating models of the solar system as a means of teaching university students astronomy. They argue that hands-on experience is a more lasting form of learning. In creating an instructional model, I am building off the findings of their research, but altering it for a different age group.

3 Procedure, Developement

3.1 Preliminary Tasks

The basis for this graphical solar system is the creation of a simple planetary model. This creation is realized by extensive experimentation with coloring and lighting in order to create recognizable planetary demos. The inclusion of the planet's axial tilt is an important inclusion of these models.

It was then important to experiment with lighting. Therefore, a directional light was revolved in a circle around a planetary model, causing the planet to undergo a full set of phases: waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, waning crescent, new.

3.2 Physically Accurate Planetary Motion

The planets revolve around the Sun in ellipses of varying eccentricities. These elliptical paths are determined by the physical laws of gravity. The planets move because of simulated gravitational forces acting between the planets and the Sun. Due to the complexity of elliptical motion, the planets in this preliminary model, behave as if their orbits are circular, though they are not. The simulation of physically accurate gravitationally generated motion is obtained using Newton's Universal Law of Gravitation, and the leapfrog algorithm, a description of which can be found in the appendices of this paper. Because this method requires a calculation of the planet's acceleration due to gravity, velocity, and position for each time step, the accuracy to which the planet's orbit is depicted depends upon the size of the time step.

In addition to the model being a computational simulation of gravity, it takes into account the inclinations of the planets' orbits. Thus, the planets do not rotate completely in one plane. They instead move in all three dimensions, just as they do in the real solar system.

One further physically accurate component that must be added is the rotation of the planets. Though tilted accordingly, the planets do not actually rotate yet. This is because rotation is meaningless without some kind of planetary texture to show that rotation is occuring.

3.3 User Interaction

Because this is intended as a learning program, user interaction is vitally important to the success of this project. Currently, users have the ability to zoom in and out, move the camera up, down, left, and right, and alter the scope of the model to include the solar system inward from any planet they choose. Future models will also enable users to ride the planets and focus in on a single planet in order to obtain detailed information about that planet.

3.4 Advanced Graphics

Rings are being added to planetary models. Saturn and Jupiter both currently possess rings, and Uranus' and Neptune's rings will be added to the model shortly. Furthermore, if time allows, planetary texture and moons will be incorporated into the model.

4 Wrap Up

4.1 Results

The current model consists of a graphical representation of the solar system, with all nine planets orbit the Sun. It takes into account the gravitational effect between these the planets and the Sun and the planets orbit accordingly. In deference to the educational purpose of the model, the user has extensive control over the camera. Instructions are provided for the repositioning of the camera and for changing the point of view. In-depth information about the solar system is provided in written form in a PDF file that can be accessed from the instructions, though not from the model.

4.2 Discussion

The model is rather basic in that it treats the planets' orbits as a circles with their semi-major axes as the radii of the circles, though, in reality, the planets orbit the Sun in ellipses. Similarly the planets do not rotate around their axes. Finally, neither the planets nor the Sun are textured, so they are dull representations of the actual bodies. The main goal of the project, though, is to serve an educational purpose. This goal, though not as integrated into the actual program as I would like it to be, has been accomplished. Users are provided with operating instructions in a separate program file, which in turn links to a PDF file I have created to educate them about the Solar System.

4.3 Conclusion

The model is complete, and if used properly, will serve an important educational purpose. Nonetheless, there is much room for expansion, some of which I will probably undertake myself. To begin with, the orbits of the planets in the program can be altered so that they are truly elliptical. This will further enhance students' understanding of the Solar System. Furthermore, the model does not represent the full complexity of our solar system. The addition of comets, meteors, and the Kuiper Belt would be another good expansion to the model.

5 Appendices

5.1 Appendix 1: Leapfrog Algorithm

The Leapfrog Algorithm is a method of calculating the position and velocity of an object in order to simulate an object in motion in a physically accurate manner. In this algorithm, the velocities are always half a time step out of phase with the positoins. In these equations, r is the object's position, v is its velocity, a is its acceleration, t is the time, and dt is the time step.

r(t+dt) = r(t) + dt* v(t+.5dt)

v(t+.5dt) = v(t-.5dt) + dt* a(t)

5.2 Appendix 2: Model Images

References

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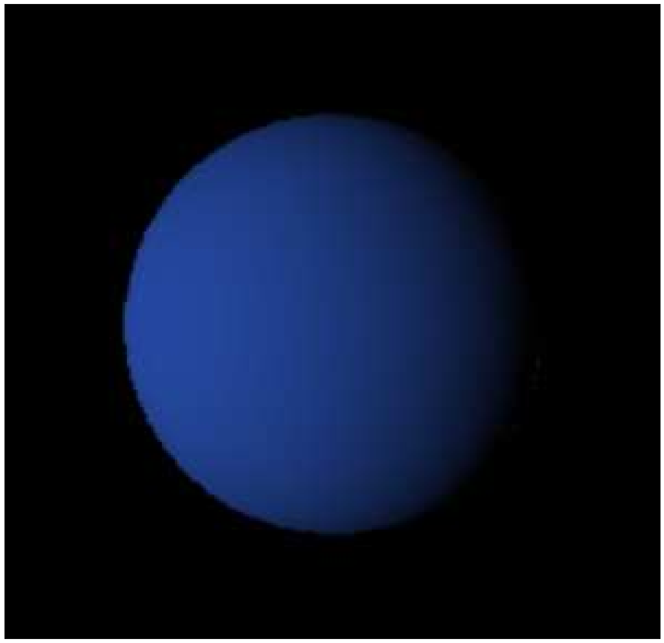

Figure 1: The planet Neptune

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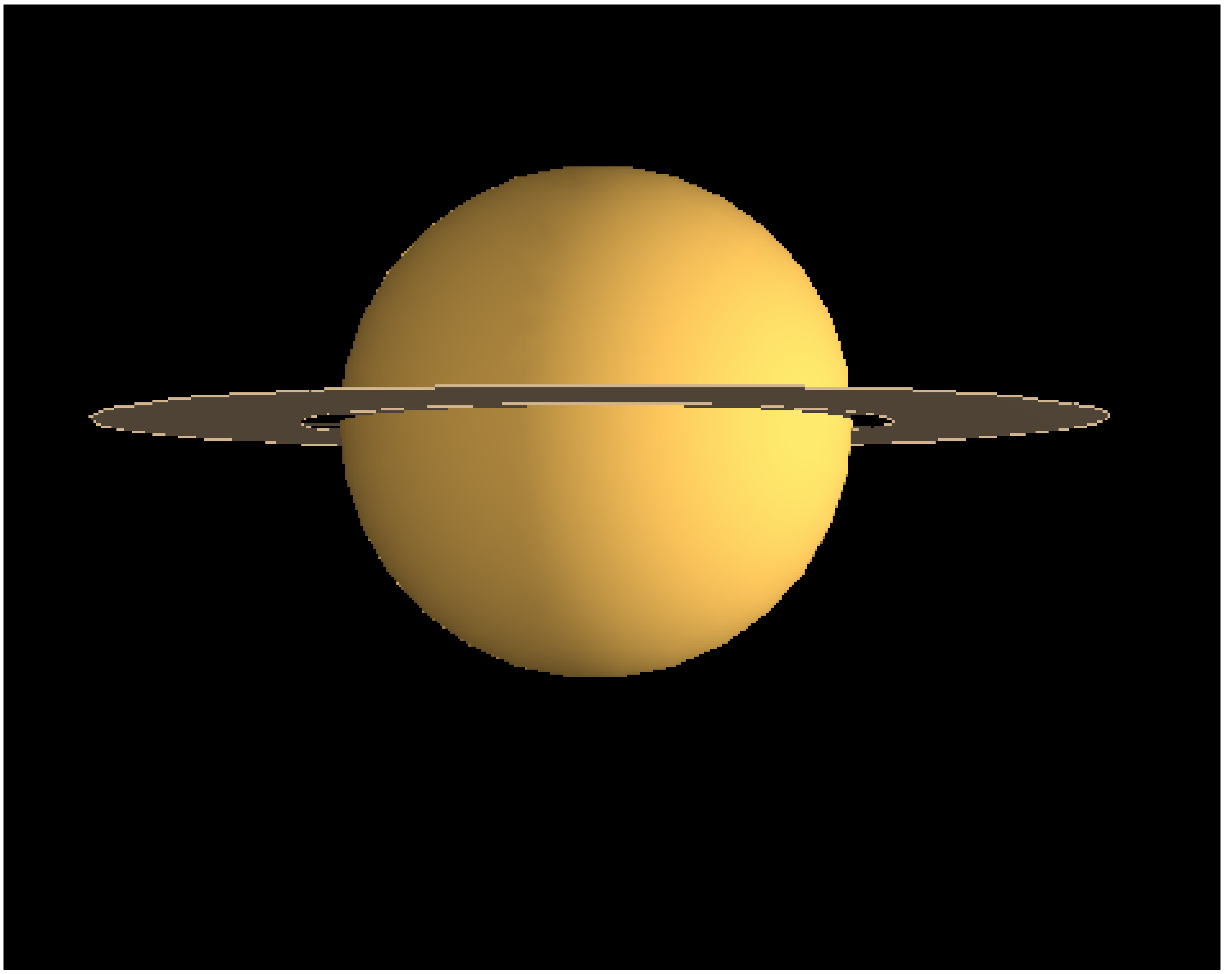

Figure 2: The planet Saturn

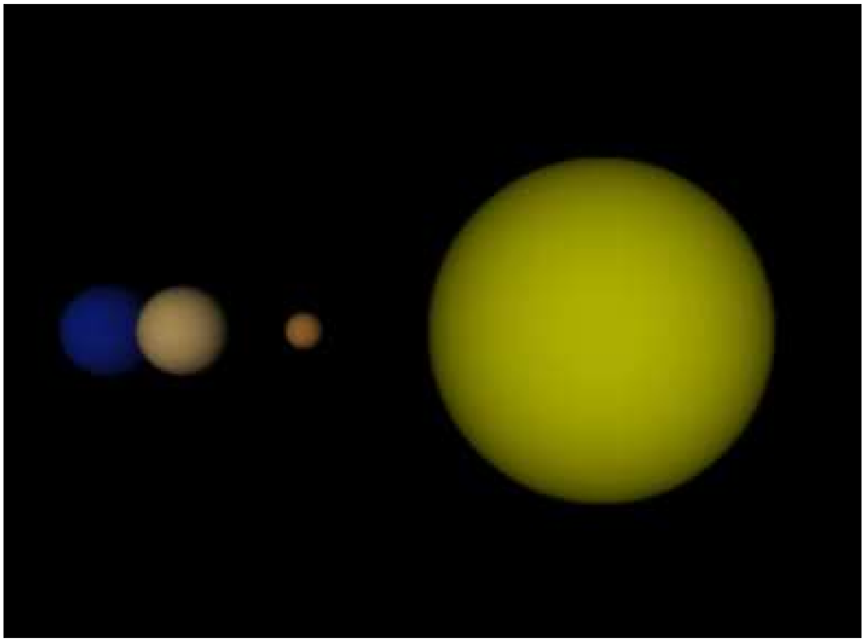

Figure 3: Mercury, Venus and Earth orbiting the Sun

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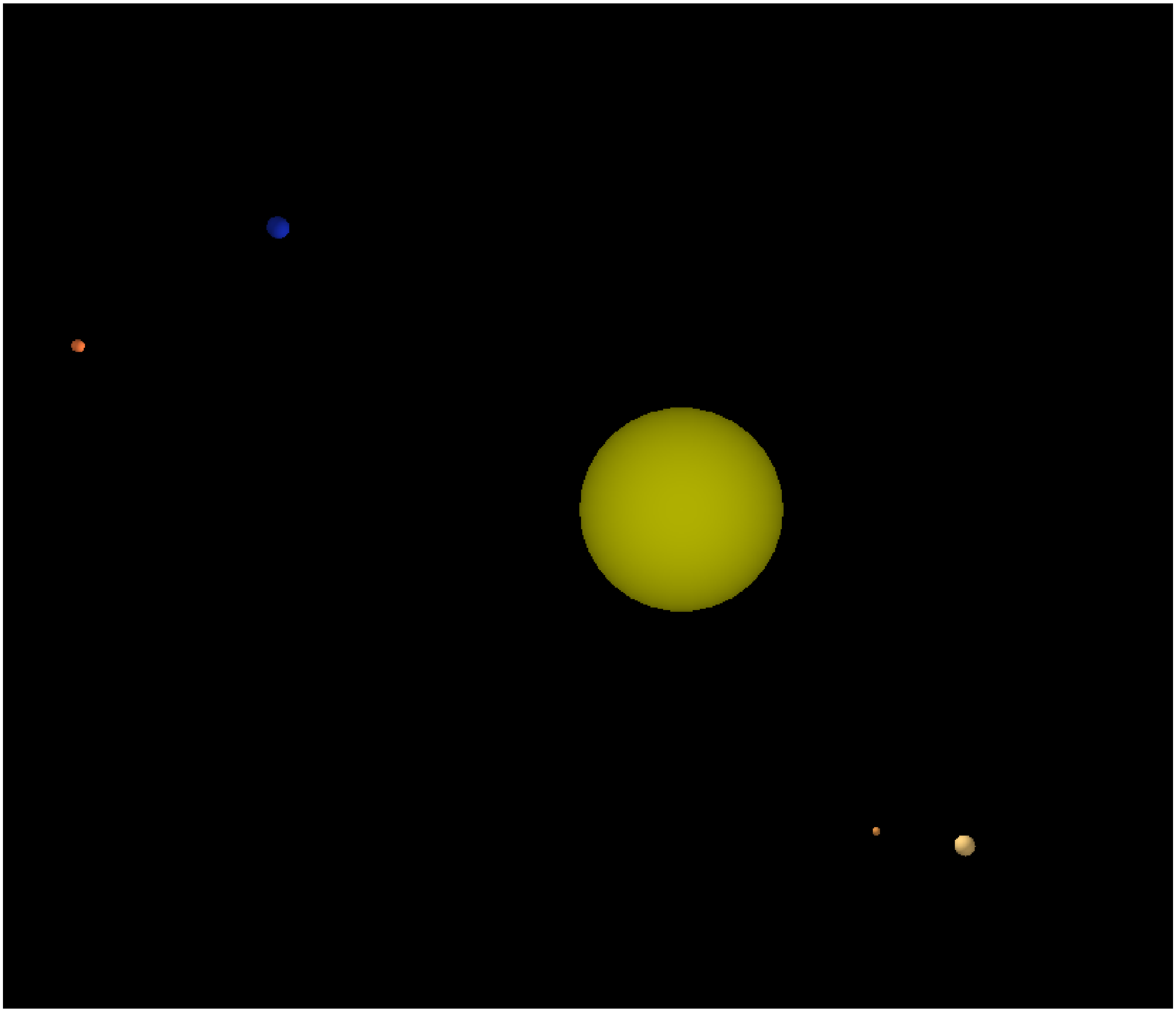

Figure 4: The Inner Solar System