## **Avoiding a Collision with an Asteroid**

# New Mexico Supercomputing Challenge Final Report April 1, 2014

# Team 68 Los Alamos High School

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#### **Executive Summary**

Our objective was to research asteroids, create a model of the solar system using Newton's laws and the programming language Scilab, and track the trajectory of the asteroid Apophis in the month prior to April 2029. We were successful in achieving these objectives. We also discovered that it takes an enormous amount of force to change the orbit of Apophis.

#### **Statement of problem**

Asteroids are large rocks in space left over from the formation of our solar system. The solar system formed over 4 billion years ago. During that time only dust particles and a giant gas clouds occupied the space where are solar system was to later form (Vogt 7). Gravity carried the particles together and the gas cloud formed the sun and the planets. However, some leftover dust particles still remained. Instead of becoming planets they formed into asteroids. Most asteroids are found orbiting the sun in the asteroid belt. The asteroid belt is in between the orbit of Jupiter and Mars. Huge numbers of them orbit the sun, and about 800 NEAs (near Earth asteroids) have been discovered (Vogt, 5).

Throughout Earth's 4.2 billion year old history, asteroids have always posed a threat. About 65 million years ago, an asteroid 6 miles wide collided with the Earth near present day Mexico. The collision caused earthquakes, tsunamis and fires and blocked out the sun for several months. The event is believed to have caused the extinction of the dinosaurs. Even in the last century, asteroids have collided with the Earth. These collisions include the Tunguska event in Siberia, Russia in 1908 (Hans, 4).

Our project focused on the asteroid Apophis 99942 (Greek for ancient evil Egyptian god) which will come between the Earth and our satellites in April 2029 and again in 2036. It is 325 m wide (about three football fields). A collision with this asteroid would be disastrous. An iron meteorite about half the size of Apophis was able to cause a crater .72 miles across called the Barringer Crater found in Arizona. (Hans, 26). Apophis is predicted to come within 2-3 Earth diameters in 2029 and have a much lower risk of collision in 2036 (Bell, 498). Fortunately scientists have determined that it will miss the Earth.

Our objective was to research asteroids, create a model of the solar system using Newton's laws and the programming language Scilab and track the trajectory of the asteroid Apophis in the month prior to April 2029.

## **Description of Method**

We used the following two equations from physics to develop our model (Tipler 202).

Newton's Law of Gravitation:

$$F = G \frac{m_1 m_2}{d^2}$$
$$G = 6.67 \times 10^{-11} \frac{meter^3}{kg s^2}$$

Newton's Second Law:

$$F = ma$$

In these laws, *F* represents force, *m* represents mass, *a* represents acceleration, and *d* represents the distance between the two masses.

Our computer model used the following sequence of steps. Each of these steps was executed for each time step.

1) Visit each of the celestial bodies in solar system.

2) Compute the force due to all other celestial bodies and find the components of each force in the x-, y- and z-directions.

3) Add components of each force from all celestial bodies in x-, y- and zdirections.

4) Compute the acceleration in each direction using Newton's second law.

5) Compute the new velocity of the celestial body.

6) Compute the new position of the celestial body.

**Step 2** required us to use mathematics to determine each component of force. This is illustrated in Figure 1. Here  $(x_s, y_s)$  and  $(x_E, y_E)$  represent the coordinates of two masses in the solar system. The symbols  $F_x$  and  $F_y$  represent the x- and y- components of force between the two masses given the total force F.



Figure 1: Computing components of force in two-dimensions using similar triangles.

In three dimensions, the components of force can be computed using the equations shown below.

$$F_{x} = \frac{x_{S} - x_{E}}{\sqrt{(x_{E} - x_{S})^{2} + (y_{E} - y_{S})^{2} + (z_{E} - z_{S})^{2}}} F$$

$$F_{y} = \frac{y_{s} - y_{E}}{\sqrt{(x_{E} - x_{s})^{2} + (y_{E} - y_{s})^{2} + (z_{E} - z_{s})^{2}}} F$$

$$F_{z} = \frac{z_{s} - z_{E}}{\sqrt{(x_{E} - x_{s})^{2} + (y_{E} - y_{s})^{2} + (z_{E} - z_{s})^{2}}} F$$

**Step 4** used the following equations to compute the acceleration in the x-, y- and zdirections. These are based on Newton's second law.

$$a_x = \frac{F_x^{Net}}{m}$$
  $a_y = \frac{F_y^{Net}}{m}$   $a_z = \frac{F_z^{Net}}{m}$ 

**Step 5** used the following equations to compute the new velocity of the celestial body in the x-, y- and z- directions. The last equation shows how each equation can be derived from the definition of acceleration.

$$v_x^{new} = v_x^{old} + \Delta t \, a_x$$

$$v_y^{new} = v_y^{old} + \Delta t \, a_y$$

$$v_z^{new} = v_z^{old} + \Delta t \, a_z$$

$$\Delta t : small increment in time$$

$$a = \frac{\Delta v}{\Delta t} = \frac{v_{new} - v_{old}}{\Delta t}$$

**Step 6** used the following equations to compute the new position of the celestial body in our solar system. Its position was tracked using its x-, y- and z- coordinates. The last equation shows how each equation can be derived using the definition of velocity.

$$x^{new} = x^{old} + \Delta t v_x^{new}$$
$$y^{new} = y^{old} + \Delta t v_y^{new}$$
$$z^{new} = z^{old} + \Delta t v_z^{new}$$
$$v = \frac{\Delta x}{\Delta t} = \frac{x^{new} - x^{old}}{\Delta t}$$

Here is a portion of the Scilab code we used to accomplish these tasks.

#### for i = 1:n

```
timea(i) = dt*double(i-1);
for j = 1:nbodies
   force =0;
   forcex(j) =0;
   forcey(j) =0;
   forcez(j) =0;
   for k = 1:nbodies
      if (j ~= k)
        distance = sqrt((x(j)-x(k))^{2}+(y(j)-y(k))^{2}+(z(j)-z(k))^{2});
        force = G*m(j)*m(k)/(distance^2);
        forcex(j) = forcex(j) - force*((x(j)-x(k))/distance);
        forcey(j) = forcey(j) - force*((y(j)-y(k))/distance);
        forcez(j) = forcez(j) - force*((z(j)-z(k))/distance);
      end
end
for j = 1:nbodies
   ax(j) = forcex(j)/m(j);
   ay(j) = forcey(j)/m(j);
   az(j) = forcez(j)/m(j);
   vx(j) = vx(j) + ax(j)^*dt;
```

```
az(j) = 101 cez(j)/11(j);

vx(j) = vx(j) + ax(j)*dt;

vz(j) = vz(j) + az(j)*dt;

x(j) = x(j) + vx(j)*dt;

y(j) = y(j) + vy(j)*dt;

z(j) = z(j) + vz(j)*dt
```

end

... More code

end

### Validating the Model

We validated our model by using data from NASA. We compared NASA's trajectory of Apophis with our model. Figure 2 shows the result.



Figure 2: NASA's data plotted against our model data.

In Figure 2, we took data from NASA on Apophis' position relative to the sun from March 13, 2029 until April 13, 2029. From this data, we graphed the x, y, and z positions of Apophis and compared these positions with our model predictions. Our model used a time step of one hour and **only** relied on the position and velocity of Apophis from NASA **at the beginning** of the first hour. Figure 2 shows that our model of Apophis was accurate and that our program worked correctly.





Figure 3 shows a simulation of the solar system which our model produced given the initial position and velocity of each celestial body. The different colors represent different planet orbits. Although Figure 3 only plots Jupiter and the inner planets,



we did model the other planets as well. The planets beyond Jupiter are not shown because they have very large orbits compared to the inner planets.

Figures 4, 5 and 6 show different views of Apophis as it passes by Earth.



Figure 4: Viewpoint 1 of Apophis passing by the Earth.



Figure 5: Viewpoint 2 of Apophis passing by the Earth.



Figure 6: Viewpoint 3 of Apophis passing by the Earth.



Figure 7: Apophis passing by the Earth on a larger scale.

Figures 7 and 8 show another view of Apophis passing by the Earth. We use a larger scale to encompass more of the trajectory of the Earth, the moon and Apophis.



Figure 8: Our simulation of Apophis passing by the Earth.

Figure 9 shows the result of applying 50 million Newtons of force for 200 hours in the positive x-direction on the asteroid Apophis.





### Conclusions

We were able to build a model of the solar system and predict the orbit of Apophis with our model using Newton's Law of Gravitation and Newton's second law. We also realized it would take a very large amount of energy acting over a long period of time to change the orbit of Apophis.

## Significant achievement

We created a fully functioning solar system, validated the orbit of Apophis with NASA's data, and simulated the near miss on April 13, 2013.

## Acknowledgements

We would like to acknowledge the free programming language Scilab <u>http://www.scilab.org</u> and the NASA website, <u>http://ssd.jpl.nasa.gov/?horizons</u>, which we used to extract our position and velocity data. The data from this site was also used to validate our Apophis trajectory. We would also like to thank our dad for helping us with the mathematics.

## **Works Cited**

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