Newton

A Simple Simulation of the Solar System

Newton is a simulation of the movement of massive objects (planets) under the influence of their mutual gravitational attraction. It is *simple*, because there are no sophisticated algorithms to improve the accuracy of the calculations. As a matter of fact, all calculations are done in plain double precision arithmetic as provided by `java.lang.Math` and the only physical law used is Newton's law of universal gravitation. No relativistic corrections are made and no other forces, like Solar wind etc. are taken into account.

The following features are supported by the program:

- The data of the Solar planets (incl. Pluto) are predefined within the program.
- As a default, planets from Mercury to Mars and the Earth's Moon are part of the simulation, but you can add and remove planets ('commenting them out') within a *Planet Editor*.
- The *Planet Editor* allows to specify additional objects with their mass, initial position and initial velocity as well as by their orbital elements.
- Several fictional objects are predefined, e.g. an Anti-Earth (Futura), which has exactly the mass of the Earth, but with mirror symmetric position and velocity relative to the Sun.
- Start the simulation (for the Solar planets) at any specified time in the range 1800 to 2050.
- Pause and restart the simulation at any moment.
- Control the speed and the precision of the simulation by changing parameters on the fly (hitting control-keys).
- Run the simulation in background for a specified time (up to 20000 years).
- Overlay simulations (e.g. to compare planet positions at different times).

Installation

The program is written in Java, so you have to install a JRE on your system (see http://www.oracle.com/technetwork/java/javase/downloads/jre8-downloads-2133155.html) .

Unfortunately, several Linux distributions have a so called `openjdk` preinstalled, which in most cases is out-of-date. This should be deinstalled by `sudo apt-get remove --purge openjdk*`, and the original JRE by Oracle should be installed. The latter is found at https://launchpad.net/~webupd8team/+archive/ubuntu/java and some other sites.

Unpack the file `Newton.zip` into any directory. If the JRE is correctly installed, you can start the program simply by double clicking on the file `Newton.jar` (with Linux you may have to create a program starter, or you may start it from a console).

The program does not modify any files on your computer (with exception of a file that may take a snapshot of the simulation) and does not require any input files either (with exception of this help file). However you may save and restore planet configurations within the Planet Editor by copy and paste via the clipboard.

For the Impatient

After starting the program, a frame with black background (the *Universe*) becomes visible. You may immediately start the simulation with default values by hitting the key **[SHIFT-G]** or simply **[g].** The default planet system contains the planets Mercury, Venus, Earth and Mars, the Moon of the Earth and (of course) the Sun. The simulation starts at 2004-06-08, which is the date of a transit of Venus, so check that Venus is exactly between Sun and Earth at the beginning. You recognize the Earth by the undulating path of the Moon, wobbling around the blue path of the Earth. Note that the radial part of the Moon's path is stretched by some factor, to become distinguishable from the path of the Earth (more about this later). You may stop and restart the simulation by hitting the **[PAUSE]** key and you may clear the screen by hitting the **[DEL]** key (in German **[ENTF]**).

Hitting the **[F12]** key will open the *Planet System Control* window, which allows several modifications of the objects in the universe. As a first try, replace the mass of Mercury (the number next to the name of the planet with value 3.30200e+23) by the mass of the Sun (copy and paste the value 1.9884e+30 from the first line), thereby creating a double-star system. Then give the focus to the *Universe* frame by clicking on it and hit **[SHIFT-G]**.

Control of the Universe Frame

The *Universe Frame* is controlled by the keyboard. The following codes are available:

[g] Start the simulation with the set of planets and the start time given in the Planet Editor window. If there are syntax errors in the planet specifications, the *Planet System Control* window is shown (if not already visible), an error message is given in the *Planet System Control* window and the simulation is not started. In contrast to the **[SHIFT-G]** key the track of an old simulation is not cleared before drawing the new one, so you may compare e.g. simulations with different start time.

[SHIFT-G] Start the simulation with the set of planets and the start time given in the Planet Editor window. If there are syntax errors in the planet specifications, the *Planet System Control* window is shown (if not already visible), an error message is given in the *Planet System Control* window and the simulation is not started. In contrast to the **[g]** key the track of an old simulation is cleared before drawing the new one (the old simulation is completely forgotten).

[PAUSE] Stops and restarts the simulation. Some functions of the *Planet System Control* window are only available, if the simulation is stopped (in pause state). If you restart a simulation by **[PAUSE]** after modifications in the *Planet System Control* window, the modifications will not be applied, use **[g]** or **[SHIFT-G]** instead.

[DEL] or **[ENTF]** Clears the universe without stopping the simulation. You may hit this key if the tracks of the planets have become confusing.

[d] / **[SHIFT-D]** Decrease or increase the time increment (Δt) for each step of the simulation (default is Δt = 2000 sec). The continuous flow of the real time is divided into ticks, which are separated by Δt , and the new positions and velocities of the planets are computed at every tick. Small values of Δt increase the precision of the simulation but decrease its speed. Large values do the opposite. The current value of Δt is displayed in the status line of the window.

[t] / **[SHIFT-T]** Decrease or increase the timer delay of the Java timer, which triggers the simulation (default is 20 msec). Small values speed up the simulation, large values slow them down. The precision of the simulation is not influenced by timer delay. The current value of the timer delay is displayed in the status line of the window.

[h] / **[SHIFT-H]** Decrease or increase the number of 'hidden steps', that is the number of steps that the simulation is advanced without drawing a new picture (default is 20 steps). Large values speed up the simulation, but the drawing gets coarser, small values slow down the simulation but the drawing gets finer. *Hitting* **[SHIFT-H]** *several times is the easiest way to speed up the simulation considerably*. If you want to advance the simulation in the background by a really great number of steps (say by 2000 years), use the appropriate function in the *Planet System Control* window. The current value of the hidden steps is displayed in the status line of the window.

[m] / **[SHIFT-M]** Decrease or increase the stretch of the radial component of the Moons path (default is a factor of 20). The distance of the Moon from the Earth is only about 1/390 the distance of Earth from the Sun. So the path of the Mood would be hardly visible, when drawn at the same scale as the path's of the planets. The stretch may be applied to other planet-moon-systems too (see below). The current value of the moon stretch is displayed in the status line of the window.

[SPACE] When hit while the simulation is running, a line is drawn between a planet and all its *joined* partners (see below). E.g. if you declare both Saturn and Jupiter as *joined* to Earth, lines are drawn from Earth to Saturn and Jupiter and you can see, that at 2000-05-31 there was indeed a conjunction of the two planets.

[p] Resets all parameters modified by **[d],[t], [h]** and **[m]** to its default values. **[p]** stands for 'panic'.

[F12] Opens the *Planet System Control* window (see below).

[F1] Displays this help file with your system's default PDF viewer.

The Planet System Control Window

The *Planet System Control* window allows several modifications of the current configuration of planets in the simulation. Note that all modifications are done via the planet descriptions in the *Planet Editor* (the text area in the top right corner of the window). E.g. the change of start time modifies the positions and velocities specified in the *Planet Editor*. These modifications are effective only after a restart of the simulation by hitting **[g]** or **[SHIFT-G]**. The reason is, to allow additional modifications 'by hand' or by copy and paste of the planet configuration after these 'automatic' modifications.

The Planet Editor

The *Planet Editor* contains several lines with planet descriptions. Lines prefixed with '#' are not evaluated, so you can add comments or 'comment out' objects that shall not be part of the current simulation. The planet descriptions may be given in two forms: by *Cartesian positions and velocities* or by *Keplerian orbital elements*. The simulation works with positions and velocities, so any description by Keplerian orbital elements will be converted to Cartesian coordinates before starting the simulation. The conversion requires the specification of a *time*, for which the coordinates are computed. This time is also specified via the *Planet System Control* window (see below).

It is recommended to apply changes of the planetary data to the position-velocity form only, because changes to Keplerian elements may have unpredictable consequences, unless you are a professional astronomer and know exactly what you do. On the other hand you may easily reduce the velocity e.g. of Mars by a small amount and see what happens. The Keplerian format should be used only, if you want to add other bodies, e.g. Asteroids or Comets to the simulation and copy their data from astronomical almanacs or from websites like https://ssd.jpl.nasa.gov/sbdb.cgi.

Position Velocity Form

The *position velocity form* expects the following input:

name, mass [kg], x [m], y [m], vx [m/sec], vy [m/sec], color, coupled, joined

All items must be separated by commas. The coordinates are oriented like those used by https://ssd.jpl.nasa.gov/?ss_inner, that is they represent a view from above the ecliptic plane with spring equinox at 9 o'clock and Orion roughly in 1 o'clock direction. Have a look at the predefined planets to get a feeling for the magnitudes.

The field *color* specifies the color used to draw the track of the planet. You may use the names of (almost) all colors known to HTML as specified on the page https://www.w3schools.com/colors/colors_names.asp.

The field *coupled* may be empty or contains the name of another planet, which must exist in the current planetary configuration. The field specifies the name of the mother planet within a planet-moon configuration, which will be used to compute the amount of stretch of the moon's path relative to the path of its mother planet (see above). E.g. the field coupled for the Earth's Moon contains the name *Earth*.

The field *joined* may be empty or contains the name of another planet, which must exist in the current planetary configuration. The field will be evaluated if the user hits the **[SPACE]** key while the simulation is running, which results in drawing a line between the planet and its *joined* partner (see above).

If the parameter *joined* or both *coupled* and *joined* are omitted, the trailing comma(s) need not to be written. If only *coupled* is omitted, *joined* must be separated by two commas.

Keplerian Elements

The *Keplerian elements form* expects the following input:

name, mass [kg], a [AU], e [1], I [deg], node [deg], peri [deg], M [deg], epoch [JD], color, coupled, joined

All items must be separated by commas. The fields *name, mass, color, coupled* and *joined* have the same meaning as in the *position velocity* form.

a – semi major axis in Astronomical Units
e – eccentricity in radians

I – inclination in degrees
node – longitude of the ascending node in degrees (also called Ω in some publications)
peri – argument of perihelion in degrees (also called ω in some publications)
M – mean anomaly in degrees
epoch – time for which the data are valid as Julian Day

Input is assumed to be in Keplerian form, if it contains at least 10 comma separated items. Be careful not to confuse the *mean* argument of perihelion (often called $\tilde{\omega}$) with ω. Compute the latter by the formula $\omega = \tilde{\omega} - \Omega$.

Examples (from https://ssd.jpl.nasa.gov/sbdb.cgi#top) :

Ceres, 9.393e+20 , 2.767409, 0.0756073, 10.59322, 80.30888, 73.023743, 309.494055, 2458000.5, white
Pallas,   2.34e+20, 2.773085, 0.2305974, 34.83792, 173.08717, 309.991558, 291.651363, 2458000.5, cyan

You may be surprised by the strange appearance of the path of asteroid Pallas. This is an effect of the great inclination of this asteroid (34.8°) and the (primitive) way in which the program deals with the three-dimensionality of the solar system (by simple forgetting the z-component relative to the ecliptic). You may look at a more sophisticated 3d-simulation like https://theskylive.com/3dsolarsystem to see a realistic path of Pallas.

The Message Area

The text field below the Planet Editor is called Message Area. It is used for the output of messages of all kinds, e.g. confirmation messages or error messages. You may also print the current positions and velocities of the planets to this area in order to copy it to the clipboard and use it in a later session.

The Date Picker

On the top of the left side there is a combo box, which allows the selection of the start date for the simulation. You may enter every valid date in the form YYYY-MM-DD between 1800-01-01 and 2050-12-32. Several dates of known astronomical events are predefined and may be selected. You may also enter a comment with your date, then the date must be included in parentheses, e.g. 'Bloomsday (1904-06-16)'. If you enter or select a date, you will notice that the Planet Editor is updated, because new positions and velocities are computed for that new date. These new data become effective, only if the simulation is (re)started by hitting the **[g]** or the **[SHIFT-G]** key.

The Background Button

Clicking on this button will start the simulation in background (without drawing to the Universe) for a specified amount of years. The number of years may be selected by the slider below this button. The background simulation may take several minutes, especially if there exist a lot of objects in the planetary system (e.g. debris from planet explosions). The end of the simulation is indicated by a message in the Message Area. After this you may hit the **[PAUSE]** key to continue the drawing to the *Universe*. Note, that you must not hit **[g]** to continue, because this will re-read the data from the *Planet Editor.* Note also, that the whole planetary system may shift out of the visible area during background simulation. So it is recommended to set the checkbox '*Pause at exit from screen*' (see below).

The Restore Button

A click on this button fills the *Planet Editor* with the default planet configuration, displayed also at start of the program.

The Print Button

Prints the current planet configuration to the *Message Area* in a form that may be used to be copied to the *Planet Editor*.

The Snapshot Button

Saves a snapshot of the *Universe* to a file. The user is prompted to give the name of the file, which must be of the type `jpg`, `png`, `gif` or `bmp`.

The Checkboxes

Draw requested lines at start. If selected, a line between 'joined' planets is drawn immediately after start or restart of the simulation. The same effect would be reached if you hit **[SPACE]** in the very first moment after start (but that would be a sportive challenge).

Pause at Collision. If selected the simulation will stop if two objects collide (see following paragraph).

Pause at Rupture. If selected the simulation will stop if an object is torn apart due to extreme acceleration (see following paragraph).

Pause at exit from screen. If selected the simulation will stop if an object leaves the visible area of the Universe.

Don't track. If selected the path of the planets will not be drawn. You will see only small dots moving around.

White Background. If selected the Universe will be painted with a white background. This may be better, if you want to save a snapshot of the Universe to a file. Note that with this option selected the colors of the planets may be replaced automatically by darker alternatives to increase visibility. When a simulation is running, hit **[DEL]** after (un)selecting the box, to redraw the Universe with new background.

Astronomical Exactness

As already mentioned the program is 'simple'. It is not intended to locate planets in the sky and is not exact to the hour. Especially the path of the Moon is not realistic, because it is not computed from orbital elements but by the following simple rule of thumb: Get the distance Earth-Sun, add 405500 km (the apoapsis), compute x- and y-coordinates from this distance elongating the line segment from Sun to Earth, get the orbital speed of Earth, add 964 m/sec (minimal orbital speed of Moon), compute vx and vy, assuming that the speed vector of the Moon is parallel to that of the Earth, when Earth and Moon are in conjunction with the Sun. As a consequence of this simplistic view, the simulation will always start with a 'full moon'.

The primitive way by which the program handles the three-dimensionality of the solar system has already been mentioned above. This is tolerable for objects with small inclination (like most of the planets) but leads to a distorted view in case of great inclinations.

Another unrealistic presentation takes place in case of near encounters of planets. If the distance of two bodies becomes less than 30000 km (roughly the distance of geo-stationary satellites from Earth), a collision is assumed and the objects are melted to one body with a mass equal to the sum of masses of the collided objects and a velocity computed by application of the momentum conservation law. In many cases of near encounters the planets do not collide, but they gain extreme velocities. If the velocity of a body exceeds 3000 km/sec (roughly 50 times the speed with which comet Shoemaker–Levy hit Jupiter in 1994), it is assumed that the object is torn apart. The resulting debris is accelerated into random directions, respecting only the momentum conservation law.

Examples

1. Erase the '#' for Jupiter in the *Planet Editor*. Suffix the data of Jupiter and of Venus by ', , Earth' (making them joined to Earth). Enter the date 1818-01-03 into the *Date Picker*. Check the Checkbox 'Draw requested lines at start'. Run the simulation by hitting **[SHIFT-G]**. You will see the rare astronomical event of Venus occulting Jupiter. The next Venus-Jupiter occultation will be 2065-11-22, but this date is outside of the allowed range for the start date.
2. However, you may start a simulation at 2050-12-31, run it in the background for 14 years, restarting a few days after 2064-12-31 (by hitting **[PAUSE]**) and stop again when the day count reaches 5440. At this moment the next Venus-Jupiter occultation should be visible. It may be helpful to check the *'Don't track'* checkbox, to be not confused by the paths.
3. Restore default configuration (if necessary). Let it run for a few days, then hit **[PAUSE]**. Prefix the line of the Sun in the *PlanetEditor* with '#' (commenting it out). Restart the simulation with **[g]**. You will see the planets flying away on straight lines. However, the Earth will keep its Moon as a companion.
4. Restore default configuration (if necessary). Erase the '#' before *XJupiter*. You should also *decouple* the Moon from Earth by erasing the string ', Earth' from the definition line of the Moon, to get a more realistic picture. You will then watch the inner planets heavily disturbed by a Jupiter size object running on an eccentric ellipse.
5. Restore default configuration (if necessary). Erase the '#' before *Tumbler*. You will watch a Moon size object falling straight into the Sun and being disrupted by tidal forces.
6. Restore default configuration (if necessary). Erase the '#' before *Futura*. You will watch a planet configuration with an Anti-Earth (but without a Anti-Moon). Hit **[SPACE]** sometimes to see that the Anti-Earth Futura is always hidden behind the Sun (seen from Earth). You may hit **[PAUSE]** and simulate the next 20000 years in background (this takes roughly 2 minutes on my computer). Continue the visible simulation by hitting **[PAUSE]** again. Besides of the fact that the whole planet system has moved, you will see that the line of sight between Futura and Earth does not run through the Sun anymore (hit **[SPACE]** to verify this). So the configuration seems to be unstable in the long term.
7. Erase all objects from *the Planet Editor*. Copy and paste the following objects to the *PlanetEditor*

```
Sun, 1.9884e+30, -2.0e+11, -2.0e+11, 0, 0, yellow
O1, 1.0e+4, 2.0e+11, 2.0e+11, 0, 0, red
O2, 1.0e+4, 2.1e+11, 2.0e+11, 0, 0, white
O3, 1.0e+4, 2.0e+11, 2.1e+11, 0, 0, green
```

O4, 1.0e+4, 2.1e+11, 2.1e+11, 0, 0, orange

Select the checkbox *'Don't track'*, so that no path does obscure the moving objects. You will see that the relative position of the objects is stretched from an almost quadratic form to an oblong diamond shaped form. The effect is the same as with the deformation of the almost spherical shape of the Earth's ocean surface to an ellipsoid with *two* bulks by the tidal forces within the Earth-Moon-system. The example shows that these tidal forces act also on free falling bodies (actually the Earth and Moon *are* free falling around their common barycenter). There is no rotation and no 'centrifugal force' responsible, it's only the field gradient of the attractive force between the objects, which causes tidal effects.