Solar System Simulator – Technical Notes

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Introduction

The Solar System Simulator is written in Java. Positions and velocities of 24 Solar System bodies are continuously updated using either Newton Mechanics or General Relativity. Initial positions and velocities are obtained from Nasa JPL's ephemerides. While simulating, both simulated positions and ephemeris data are visualised for comparison. Source code is made publicly availaible under the MIT licence.

Simulation

Position and velocity of each particle is updated each time step using a Runge-Kutta scheme. Computing acceleration requires interaction between all pairs of particles, and therefore, the simulation is computationally expensive. Although Newton Mechanics with a time step of 1 hour suffices in most cases, a smaller time step and/or General Relativity may be applied to obtain even more accurate simulation results, especially when bodies are moving fast (e.g. Mercury). It should be noted that General Relativity requires much more computational effort compared to Newton Mechanics.

In case you want to run longer lasting simulations (say more than a century), it is possible to run the simulation without a graphical user interface and store intermediate results. See CreateSolarSystemStateFiles.java for example code. The files can be loaded into the simulator for visual inspection and/or continuation of the simulation.

The Runge-Kutta scheme allows advancing with a negative timestep. Thus, it is also possible to simulate backward in time.

Ephemerides

Initial positions and velocities of the Solar System bodies are needed to run a simulation. In the simulator, ephemeris data is continuously computed such that simulation data (blue orbit lines) and ephemeris data (green orbit lines) can be compared at all times. Ephemerides data is computed such that the ecliptic plane corresponds to the x-y plane. In the Earth-to-Sun viewing mode, the ecliptic would be horizontal, whereas in reality the ecliptic plane would be tilted due to the fact that the Earth’s axis is tilted. This should be noted when comparing a simulated Venus transit with drawings or pictures taken during the event.

Ephemerides for Sun, Moon, and major planets (including Pluto)

For dates between December 4, 1899 and February 1, 2200, DE405 is used. For other dates between 3000 BC and AD 3000, an approximate ephemeris is being used. Ephemerides data for the Moon before December 4, 1899 or after February 1, 2200 is approximated using DE405 ephemeris data (see EphemerisSolarSystem.java for the code).

Ephemerides for remaining Solar System bodies

Ephemeris data for the remaining bodies is computed from orbital parameters obtained from the JPL Small-Body Database browser.

Example event in the Solar System

On September 1, 2017, Asteroid 3122 Florence passed the Earth at a distance of about 7066000 km. In Table 1, ephemeris data is compared to simulation results obtained with Newton Mechanics and General Relativity. Simulation was started at April 1, 2017 with time steps of 1 minute and 1 hour, respectively. See FlorenceEarthExperiment.java for the code. It can be observed that simulation data deviates from the ephemeris data. This is due to the gravitational pull of the Earth-Moon system on Florence.

Method	**Timestep**	**Min Distance**	**Date/time**
Ephemeris	1 minute	7066675.82 km	2017-09-01 12:07
Ephemeris	1 hour	7066677.97 km	2017-09-01 12:00
Newton Mechanics	1 minute	7053326.41 km	2017-09-01 11:55
Newton Mechanics	1 hour	7053327.51 km	2017-09-01 12:00
General Relativity	1 minute	7053314.52 km	2017-09-01 11:55
General Relativity	1 hour	7053315.61 km	2017-09-01 12:00

Table 1: Minimum distance between Earth and Florence, and time at which distance was minimal for ephemeris data and various methods of simulation.

Simulation accuracy

To obtain some insight in the accuracy of the simulation results, the major planets, the Sun, the Moon, and Pluto were simulated for three centuries (300 times 365 days to be precise). The simulation was started at January 1, 1900. During the simulation, the deviation in position compared to the DE405 Ephemeris was calculated each day. Average deviation was calculated each year. As may be expected, the deviation steadily increased over the years. In Table 2, the average deviation for each body is shown for the 300th simulated year. It can be observed that using General Relativity leads to more accurate results for the inner planets, whereas for the outer planets the difference is neglible. The results shown in Table 2 were obtained by running SimulationAccuracyExperiment.java.

Solar System body	**Newton Mechanics**	**General Relativity**
Mercury	49406 km	13 km
Venus	26519 km	14 km
Earth	17675 km	68 km
Moon	17990 km	5491 km
Mars	12174 km	59 km
Jupiter	893 km	419 km
Saturn	65 km	363 km
Uranus	90 km	301 km
Neptune	306 km	191 km
Pluto	162 km	125 km

Table 2: Deviation in position after 300 years of simulation.

Java code
To get an overview of the code you can generate JavaDoc. Unittests are provided for the supporting classes EphemerisUtil, JulianDataConverter, and Vector3D.

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References

Runge-Kutta numerical scheme:
http://physics.bu.edu/py502/lectures3/cmotion.pdf

Update scheme for General Relativity (see equation 27 on page 12):
https://ipnpr.jpl.nasa.gov/progress_report/42-196/196C.pdf

3122 Florence
https://en.wikipedia.org/wiki/3122_Florence

Approximate Ephemeris
https://ssd.jpl.nasa.gov/txt/aprx_pos_planets.pdf

JPL Planetary and Lunar Ephemerides
https://ssd.jpl.nasa.gov/?planet_eph_export

JPL Small-Body Database Browser
https://ssd.jpl.nasa.gov