

PLANETARIUM SIMULATION SYSTEM USABILITY AND EXPERIMENTS

Prof. Dr. W. Kowalk
FB Informatik – Universität Oldenburg, Germany
Ammerländer Heerstraße 114-128, D-26129 Oldenburg
Kowalk@informatik.uni-oldenburg.de

Abstract

This paper describes a modeling, simulation, and evaluation system for planetary simulation, including dynamic 3D-visualization, event capturing, and experiment management.

Because of the amount of information to be given, particularly presentation of detailed pictures, a first paper [3] has been published to inform about main aspects of our simulation system and in this paper we are concerned with handling of and experimenting with this system. To keep this paper self-contained, some paragraphs are abridged repeated.

Keywords

MODELLING AND SIMULATION METHODOLOGIES

3-Dimensional Modeling, Visualization, Applications

1 Introduction

Simulation of real world systems has been a long tradition, where accuracy of the results is usually the main quality feature. Although we agree to this statement, there are further important requirements for simulation systems, where visualization of an evolving simulation to convince modelers as well as customers from its plausibility, and event capturing to protocol particular incidents are only two. The simulation tool that is presented here considers several requirements for continuous time simulation systems.

We call our system **Copernicus Planetarium** in respect to a (well known) former Physician, whose problems were not only of mathematical or technical nature, but have been political as well as religious; this is to remind people of our time that progress has not only been achieved in mathematics or computer technique, but also in social tolerance and human respect.

Our system is programmed completely in Java, which has of course some drawbacks according to performance. However, on a modern computer system we can evaluate several million steps in a second, which seems to be sufficient for many applications, as will be shown later. Performance will be a special aspect in another paragraph.

Our former paper [3] explained in detail technical properties of simulation techniques, which will not be repeated

here. In the first part of the paper in hand we focus on presentation technique, which displays the movement of planets in an animated space, that can be switched to several display methods, including tracing of planet courses, three-dimensional presentation by use of red-green-glasses or different viewing perspectives. Then we will present the organizational background of our simulation system, and as a final technical discussion we are concerned with event capturing, i.e. how to protocol events like “planet arrives at the nearest point to sun (perihelion)” or “two planets crashes”, the latter of which is of interest in chaotic modeling.

In the second course of this paper we present some simulation results, which demonstrates the high accuracy of the applied technique as well as the high educational use, so that this system might be useful in education as well as astronomical planetoid simulation.

2 Usability and Utilization

We are convinced that a simulation system is particularly useful only, when its handling and even its appearance is convenient for a user. This holds for several reasons. The first one is that for an occasional user no or little care over appearance and usability means that also the underlying technique is not very well developed. A second point is that a tool should produce results, not problems, so that an easy to use tool will generate in the same time more and better results than any cumbersome, illogical interface, where little attention is paid to usability. As another point, a tool should assist the users, not patronize them. So results should be utilizable in further applications. e.g. printable figures or calculations in spreadsheets.

Thus, our simulation system focusses on both, usability and utilization. We will present our concept how to initialize a simulation run in a simple way, how to define recordable results, and how to utilize them in further applications. At first, we glance at appearance of our system.

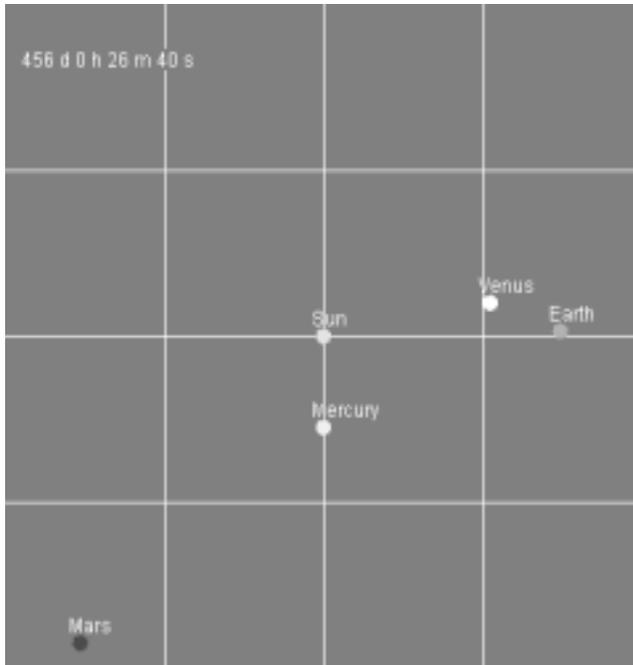
2.1 Interface

This section describes the interface of our simulation system. If you start the program there appears a panel, which controls all features of the simulation. When a simulation is started, another window pops up which is called “Space”, and in which the observer can follow the course of the planets. Further information can be displayed in text

windows, the contents of which can be stored in files. Additionally, some intermediate quantities can be displayed on the main panel. Several output windows can be maintained during simulation, so that different results can easily be compared. These features will now be considered in more detail.

Main Panel

The main window, a picture of which can be found in [3], controls all further activities. It holds the planets to be simulated in a drop down menu, controls output to the



Picture 1 - Output of a simulation run with Sun and 4 planets

In the window *Space* (Picture 1, 2, 3, 4) all planets can be displayed, as well as their current positions. The window can be scaled to each size, so that any extent can be displayed in one panel. Since the distance from the sun varies for all planets very much, this is an important feature. Other parameters are time, scale, or even background color, but also grid or view. Also the original diameter of the planets can be displayed, either linear to the real extent or scaled “logarithmically”, where the central star gets some fix size and all others are decreased to a magnitude still observable.

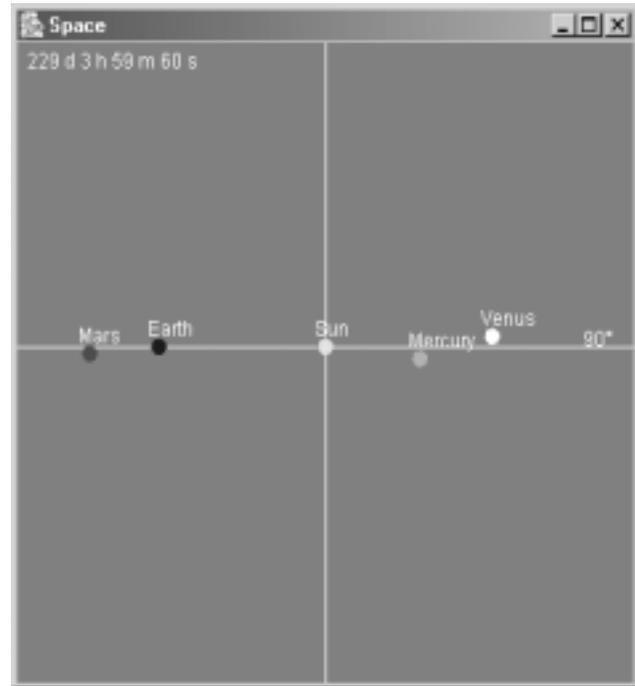
View can be changed by several parameters. For example, since we use three dimensional spatial simulation, simulation can be observed from the horizontal point of view, observing the bending from the ecliptic, the area, in which the earth rotates around the sun. Particular comets like Haley have a very large bending to the ecliptic, however Mercury’s or the Earth’s Moon’s angle to the ecliptic is also considerably large (Picture 2).

Sometimes, the trail of a planet is of interest. Observing an ellipse is of course of some interest (Picture 3), however, our simulation system allows to specify any planet as

“space”, where the planets course can be displayed, and controls several parameters of the planets. Also, new planets can be added, or existing planets removed, and file input and output controlled.

Space

There is one graphical window (called *Space*), that is used to display the animated position of the planets, while precise numerical results can always be obtained and plotted as well, although in another window.



Picture 2 - Output with an angle of 90° to Earth’s plane

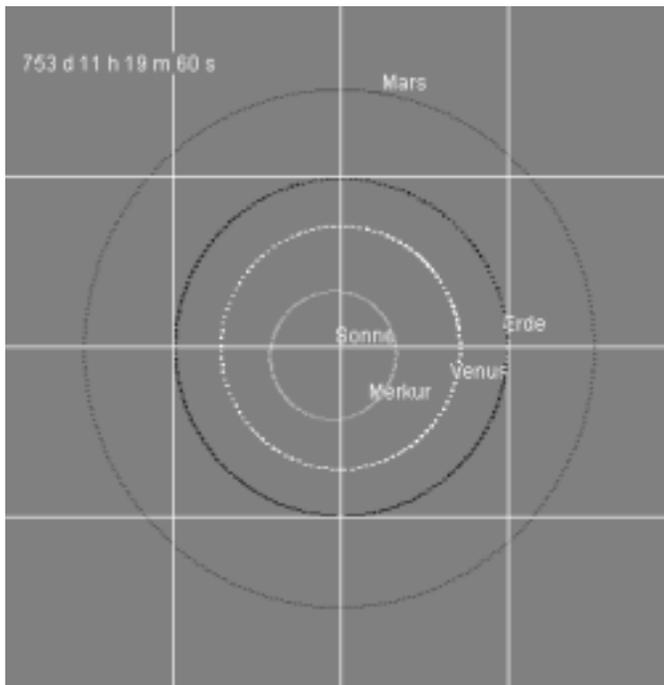
“center of observation”. Thus, instead of having the origin of the space as center, the Sun, the Earth or any other planet can become the center by pressing the button “Follow Planet”. This leads (e.g. in case of geocentric view) to very complicated trails, and it is of interest to display them (Picture 4). This can be done by clicking the “Trace” check box, where displaying the original diameter of the planets yields the output plotted in the pictures.

Animated planet movement or displaying the trail of a planet leads to very interesting results, which should help to understand such physical phenomena. Thus, this helps understanding astronomical results, which is useful for teaching and researching.

Another output features is 3D-Simulation (Picture 5). For this, the planet’s position is plotted with two color spots, usually red and green, which are separated according to geometrical estimation, so that a spatial impression is achieved with the usual view from a pair of spectacles with red-green glasses. This can also be observed while the planets are moving.

Text windows

Many exact results can be displayed in special windows, which are opened automatically, when for example Output Control is selected. Picture 6 plots the perihelion (smallest



Picture 3 - Trace of planet movement

The format of the text panel can be altered by a mouse click to assist evaluation of the data in a spread sheet (e.g. semicolon separated; in Picture 6 the data are tabulator separated). This simplifies analysis of simulation runs, even over very long period, demonstrating accuracy of the simulation system itself, or some physically relevant effects like the shift of Mercury's perihelion. We have produced all diagrams in [3] in this way by some mouse clicks.

3 Simulation

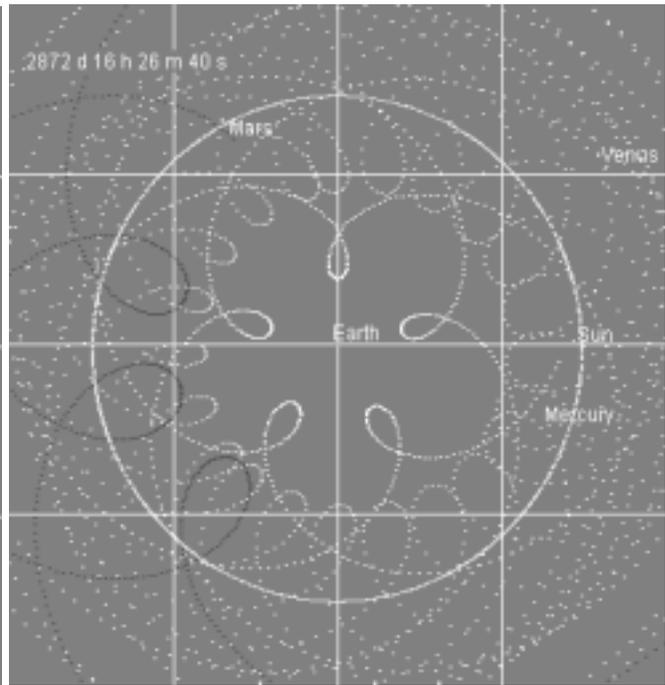
Since simulating is the main business of the program, we demonstrate some simulation examples. At first we show how simulation is to be started and managed.

3.1 Organization of Experiments

Many simulation systems provide their users with some accurate algorithms, also some advanced display techniques etc. However, it is often very cumbersome to start a new simulation, interrupt a simulation, store intermediate results or states, or continue an interrupted and stored simulation. Thus, our system sustains the user by some advanced features.

- start or restart a new simulation,
- alter parameters of a simulation, even during simulation run,
- stop a simulation, either event driven or manually, to observe intermediate results,

distance to the sun) of planet Mercury at any revolving. The simulation system allows for all planets to define events, when an output is created to a window, where each planet will get its own text window. Another text window can be defined, which lists all outputs to the status bar.



Picture 4 - Geocentric View of inner planet's traces

- store and retrieve simulation runs,
- store and evaluate singular or periodical results,
- etc.

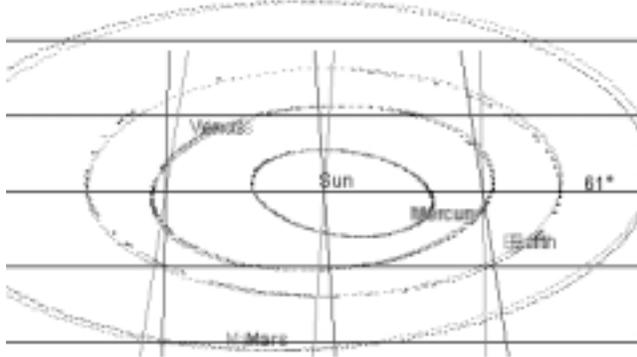
These are some features that can all be found in our simulation system.

To start a simulation the user has to provide a planet list, that can be inspected by a combo box (which is a drop down menu on the panel). Planets can be removed or added to this combo box by a mouse click. Also, planets already in the combo box can be selected or deselect to include or exclude them from next simulation run. Additionally, when the simulation run is saved to a file, this combo box is saved as well, so that any collection of special planets can be retrieved by simply opening a file.

To initialize or alter the parameters of a planet or inspect its initial or current parameters, the main panel supplies the user with a set of numerical fields, for position, velocity, mass, diameter, or name and display color of the planet. For each planet the parameters can be loaded and set by a mouse click, and are of course saved in the files.

Simulation can simply be stopped by pressing a button. After this, simulation can be continued by pressing the same button. During this stop (but also during simulation) it's possible to inspect all current parameters of the planets; they even may be altered by the user. When the simulation run is stored to a file, it can be continued after reloading it, which is very comfortable for "long" simulation runs. Thus, also intermediate backup storage is possible.

2585 d 15 h 33 m 20 s



Picture 5 - 3D-Animated output

To protocol some events, our simulation system provides some optional text panels, which are displayed only on demand (see Picture 6). These text panels can be stored into a file, if required, where precaution is provided to store them in a special format, so that those data can be reevaluated in a spread sheet to derive diagrams etc.

3.2 Examples of Simulation

We present here some examples, which seem to be of some general interest and also show the high accuracy of the simulation system. It is also important to understand that most of these results can be obtained by some mouse clicks on the interface. Easy usability is one of the main features of this program (and as important as technical properties).

3.2.1 Simulating a system of planets

As a first example, we present a simple simulation output, which is achieved from standard values. It is simply produced by clicking the “Start Simulation” button. The space window pops up and you see the sun with four planets (picture 1). Of course, it's always possible to introduce further planets or remove some. However, you get here only a changing view, not the trace of the planets. To see this, you can push the trace button. Then usually the name of the planet is plotted once and its track is never cleared (picture 3). This is very comfortable, and particular useful, when the traces are more complicated. For example, a geocentric simulation looks like displayed in picture 4. To get this view you simply have to select Earth and press the “Follow Planet” button. Then the very complicated traces can be observed, which the inner planets write on the sky.

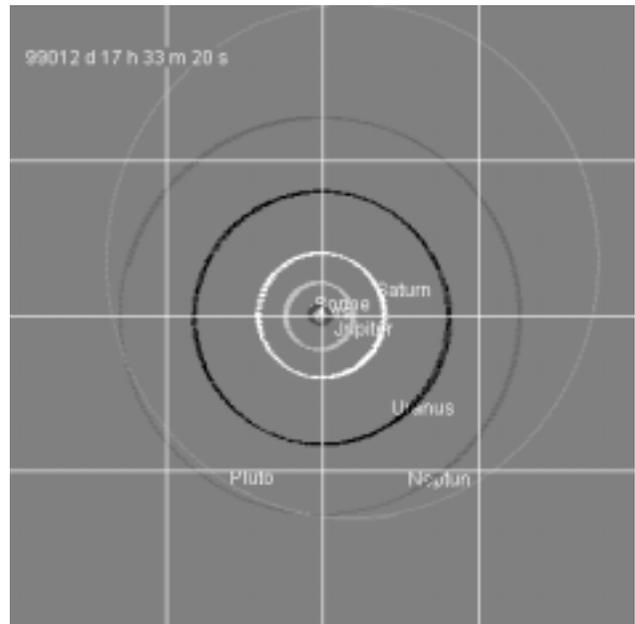
3.2.2 Simulating outer planets Pluto and Neptune

Simulation of planets looks sometimes interesting, how-



Picture 6 - A Text Window displays exact values during simulation

ever is mostly not surprising, since all planets follow a disjunctive circular (or more precisely an elliptic) course around the Sun. However, there is one exception to this rule, which are the planets Pluto and Neptune, the trace of which seem to cross. Picture 7 shows this.



Picture 7 - Trace of outer planets with course of Pluto and Neptune crossing.

This simulation has been made by using the Ephemeride-tool, explained later. It shows quite clear that the courses of the planets Pluto and Neptune cross. However, this holds only for the chosen point of view. Pluto is a special planet, since it is moving in a plane that is bent to the Earth's ecliptic with an angle of 17°, and which is therefore at the points of crossing very far away from Nep-

tune's plane, which is bend only 1.8° to the Earth's ecliptic. The result is of course astronomically very well known.

Our simulation system provides the user with the concrete initial values of the real solar system, starting at September 5, 1995, 0.00, UT. This is of course only one option, since any other initial values can be simulated.

3.2.3 Escape Velocity

As another example we present an experiment to measure a physical quantity, here escape velocity, which is the minimum speed required for an object to leave a gravitational field.

Simply select two planets, e.g. Sun and Mercury, change the initial values of Mercury, where speed is set to zero, and distance to Sun chosen arbitrarily but large enough. Select "On Collision Stop" and "Print Status in Window" from the menu. Now, start simulation. After some time, the planet will plunge into the Sun and simulation stops. The output window will display besides others a figure like: $v_x: 617520.6404468527$ m/s, which means that the planets final speed before collision with sun was about 617.5 km/s, which is the very well known escape speed for the Sun.

This example shows that simulation can produce physically relevant results, besides the simplicity how to get these quantities.

3.2.4 Measure the shift of a planet's perihelion

Another physically interesting result it to measure the alteration of the route a planet takes through space. Since the trace of a space is usually an ellipse (or another Kepler curve), we can observe its stability in space.

In a first experiment we can measure the perihelion of Mercury, which is the closest point of a planet to its Sun. When there is no other body, a very fix position of the perihelion can be measured. This is done by clicking Output Control for Mercury and starting the simulation. The result is a text window, that produces exactly the desired figure (see picture 6).

However, in a second experiment, we can perform the same simulation, using an additional planet like Venus, Earth or both of them. Performing the same experiment we can observe a slight, however measurable shift of the perihelion, which is a very important physical phenomena. A figure of this results can be found in [3].

Another physical principle can be illustrated by this example as well. For this the measurement should be made with several planets, both all together and individually. It can then be demonstrated that the influences of different planets add almost linearly, which is well know as principle of **superposition** in physics.

3.2.5 Maintaining Energy

Some physical principles can be measured by this simula-

tion system in a simple way. To illustrate the conservation of energy, the user can stop any simulation run at any time and display the topical quantities of each planet in the main panel. From position and speed both the kinetic and potential energy can be derived, and then their sum. The result is the "inner energy" of a body, i.e. the quantity that has to be constant over time, according to the principle of conservation of energy. Obviously, the system provides the user with the possibility to estimate this quantities, and to convince themselves from this important physical law.

3.2.6 Measurement of Other Physical Laws

There are other physical properties that can be measured by this simulation system. For example, the statement that the curves of the planets are ellipsis, or some of them are parables or hyperbolas, can be derived from this simulation system in a similar way as in the previous experiment.

It can also easily be demonstrated that the Sun is also moved by the other planets, and also that the total system of all planets including Sun must move, if the total pulse is not zero; the latter is done by setting the sum of the pulses of all planets to zero and observe, that the total planetary system doesn't change its position any more.

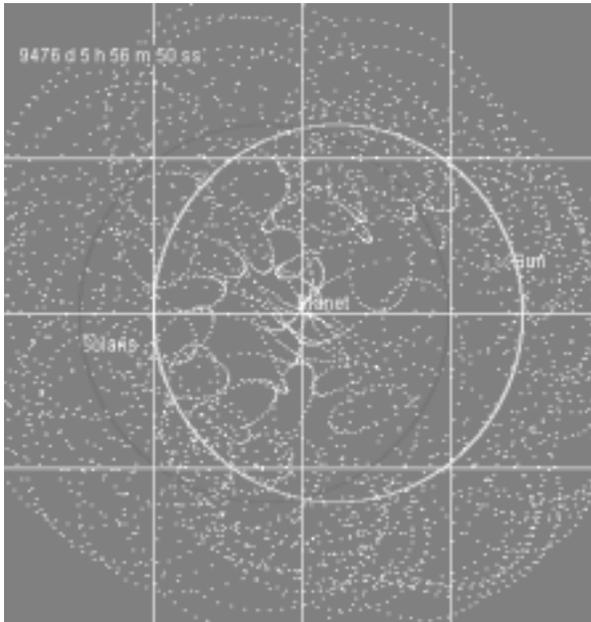
Theses examples shows that we have a fine tool to demonstrate many physical properties in a simple and clear way, which is particular useful for educational applications.

3.2.7 Chaotic Behavior of Planets

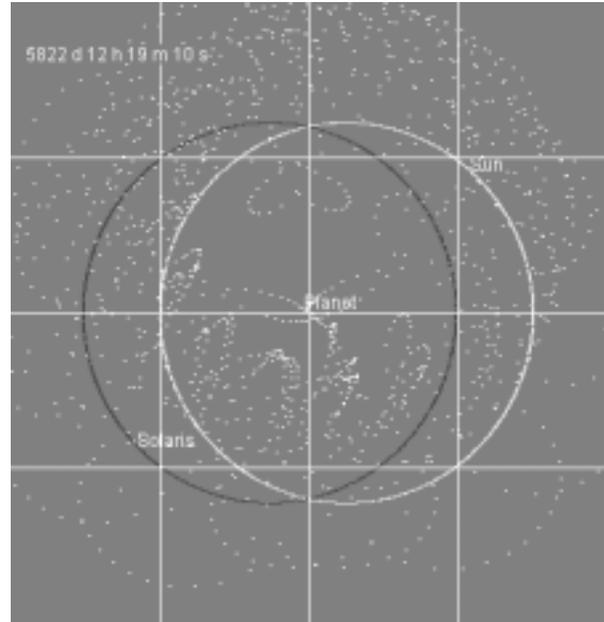
As a final result we plot a picture that shows the chaotic behavior of a three-body system, which has been used in a reading to demonstrate, that in physics many phenomena cannot be solved by exact mathematical methods; they usually require simulation, where exact simulation systems are of high importance. This shows the relevance of our simulation system, as well.

Picture 8 shows two stars, called Sun and Solaris, and a Planet. The stars are of very heavy weight and circle around each other, while the much lighter planet rests at the beginning of the simulation between the stars, with a distance of 10^{11} m between planet and each star. The planet is located at a position of about $x=10$ m. Depending on this very small deviation from origin, one of the stars attracts the planet, which is revolving around that star, and then suddenly attracted by the other star, also revolving around this one, until the planet changes again its star etc. At one time, the planet plunges to one star (which stops our simulation run).

Starting the planet at a slightly different position, e.g. 7 m instead of 10 m deviation from origin (see picture 9), the trace of the planet looks quite different, and it may finally plunge into the other star, or the same one. There seems to be no way to compute in advance, which star is hit by the planet, and which course is taken by the planet. This shows the chaotic property of the (nevertheless very simple) planetary system we have simulated here.



Picture 8 - Chaotic behavior of a planet with two suns, distance of planet to origin is 10 m.



Picture 9 - Chaotic behavior of a planet with two suns, distance of planet to origin is 7 m.

4 Further Tools

Copernicus Simulation System consists of the simulator as well as several interfaces, which have been explained in this paper. Other tools may be useful, some of which have already been implemented and installed.

One tool is used to compute exact position and speed of planets, which is required to compute from some physical data the Cartesian co-ordinates. The program is called Ephemerides and can be launched from the common interface.

5 Further developments

We plan to extend this simulation system, according to new requirements, however also according to some theoretical request. One problem to be solved is to include relativistic simulation, which means that the transformation of general theory of relativity is to be implemented. One might ask, whether the accuracy of this simulation system allows to simulate those tiny effects, but we have shown in some examples, that for example the bending of a light beam, running along the surface of the Sun yields the same result without or with relativistic simulation, when we use a simple approximation to the correct transformation. This convinces us that the high accuracy of our simulation system allows in principle to include those effects, and will yield more precise results.

However, the high precision of this simulation system shows also that results depend sensitively on physical constants and initial values. For example changing of Newton's gravitational constant at the fourth digit can alter the results of some simulation dramatically. Here follows, that the outcome of a model like our simulation system must always be compared with real world behavior.

6 Conclusions

This paper has presented a simulation system, capable to demonstrate the behavior of galactic objects like planets, meteors, or satellites. It uses a high precision simulation technique that yields much more precise results than required for realistic simulation, since other perturbations disturb the course of a planet much more than the highly accurate simulation suggests. For example, newly found planets like Quaoar [4] can easily be simulated, as has been demonstrated in [3], as well.

Besides high precision also usability of the software had been taken care for. Our system allows to store and access single objects, as well as experiments, or complete simulation runs. Results can be stored in files, or formatted so that the data can be manipulated in spread sheets; all our diagrams have been produced in this way. The interface has been kept as clear as possible, where features like internationalization or color selecting are only two.

There is a tutorial in progress (currently only in German), which shows that this simulation system can be used for educational purposes, as well. Since internationalization is considered (which will also sustain several additional important languages in near future) our system might be used for these applications as well. The simulation system can be acquired with no fee.

7 References

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