CONCEPTS FOR PROJECT GALAXY

A.R. Klumpp*, R.M. Smithwick†, D.E. Eyles‡, J.F. Jordan#, and L.H. Woeltjen§

ABSTRACT

Project Galaxy, proposed at JPL, will enable students, mission planners, and astronomy buffs to fly to any modeled planet, satellite, solar system or black hole in the galaxy or beyond. The Galaxy flight simulator will enable its pilots to observe modeled objects true to life, including their surfaces, motions, and behavior. Clicking on modeled objects produces multimedia displays of background data. Pilots can ride along on missions currently in progress, future missions now being designed, and missions which they design themselves. Relativistic effects will be modeled so that pilots can fly near light speed on round-trip missions to other stars while observing the effects on clocks, constellation shapes, etc. Users can modify and extend Galaxy's capabilities to incorporate their own flight software and hardware models, and even their own celestial bodies. Project Galaxy will provide educational partnerships, including thesis opportunities for developing new software components. The simulator is expected to serve as a repository for scientific models of celestial objects indefinitely.

* Staff Member, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, Senior Member.

† Self-employed software engineer, San Jose, California, author and producer of the award-winning astronomy program Distant Suns, nonmember of AIAA.

‡ Staff Member, CS Draper Laboratory, 555 Technology Square Cambridge, Massachusetts 02139, nonmember of AIAA.

Manager, Systems Division, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, nonmember of AIAA.

§ Managing Partner L&S Enterprises, former President of Virtual Reality Laboratories - an INC 500 company in 1996.

OVERVIEW

The purpose of Project Galaxy, proposed at NASA's Jet Propulsion Laboratory, is to build a flight simulator that enables astronomy buffs, students at all levels, and even rocket scientists to fly a spacecraft, as if piloting an airplane, to any modeled object in the Solar System, the Milky Way Galaxy, or beyond. Celestial and man-made objects are displayed true to life. Multimedia displays enable users to learn about planets, moons, stars, constellations and galaxies. Cockpit displays show the mission from a pilot's viewpoint - even relativistic effects so explorers can see for themselves that during what seems to be a short round-trip journey to a distant star, many generations of their descendants live out their lives back on Earth. Galaxy runs on PC-class computers.

Galaxy will include the latest and most realistic models of celestial-body surfaces and orbits, as developed at JPL and elsewhere. As new celestial-body, spacecraft, and mission models are developed they will be incorporated in Galaxy, and made available on the Internet to update simulators already in service. Thus explorers can ride along on manned missions and robot probes - real missions currently in progress, future missions now being designed, and missions not yet imagined. Mission planners can fly proposed missions to acquire images and measurements, and they can use the results for correcting their missions. Advanced users can extend the simulator's capability by adding their own spacecraft; their own guidance, navigation, and control capabilities; and even their own celestial bodies.

The plan is to develop Galaxy in phases spanning many years. In the first phase, we will extend the capabilities of an existing planetarium program, Distant Suns, to enable free flight as well as flying along on existing missions. Joy stick and/or arrow keys will be used for controlling translation, attitude, and pace. Pilots can choose flight modes to cause the simulator to abide by or disregard selected laws of physics. Next we will develop the capability to land on the foreign bodies, using Apollo lunar descent guidance in the lunar case. Ultimately we will incorporate accurate models of all major celestial bodies in our solar system, and many in the galaxy beyond.

Each Galaxy version will be developed using human resources and software at JPL. Educational partnerships will be established with faculty members of universities, high schools, and elementary schools, enabling thesis students to develop software modules, and students at all levels to contribute to the design.

Project Galaxy is conceived as a not-for-profit repository of scientific models of the solar system and galaxy in a form that provides easy public access. The plan is to acquire contributions from many individuals and organizations for as long as knowledge of our celestial environment continues to be accumulated.

OBJECTIVES

Project Galaxy's primary objective is to build a simulator enabling anyone with a PC-class computer with modest performance to explore all major celestial bodies in the solar system and all modeled objects in the galaxy. A secondary objective is to provide a repository for scientific models of natural and man-made objects anywhere in the galaxy.

BENEFITS

Galaxy is intended to benefit education, mission planning, and outreach.

For education, Galaxy will aid elementary and high school students in learning about planets moons, asteroids, and comets. They can see not only how these celestial bodies look, but also how they *move*. The simulator will aid college and university students in studying astrodynamics, astrophysics, and space mission design.

For mission planning, mission investigators can use the simulator to preview observations and measurements generated by hypothetical missions, feeding back simulated results for improving mission designs.

For outreach, the simulator enables the public to share in the results of NASA missions and other scientific investigations in ways that appeal to human needs for adventure and exploration. Using the simulator will be fun as well as a learning experience.

CAPABILITIES

Galaxy enables its pilot to view celestial bodies from the vantage point of a spacecraft that can fly anywhere in the galaxy. Celestial bodies are accurately modeled and rendered, so that each image appears to be a photograph taken by a real spacecraft at its simulated location. Rendering is computed on the basis of the object's topography, lighting, and position with respect to the simulated spacecraft. Dynamic rendering (rendering on demand) makes it possible for the simulated spacecraft to travel anywhere in three-dimensional space, causing an infinite number of images to be generated and displayed. Dynamic rendering contrasts with the much more common static rendering (for example, movies), which is limited to a one-dimensional path that provides a finite set of images.

Flight Modes

The pilot selects one of three flight modes:

- In the *mission* mode, the simulated spacecraft is attached to a predefined trajectory such as one already flown or planned. Apollo, Voyager, Galileo, and Cassini trajectories are examples. The trajectory can also be one already generated by the user. In the mission mode, the pilot controls the pace, making it possible to travel from Earth to Jupiter, for example, in a few seconds, and then move as slowly as desired while viewing Jupiter or one of its moons. For mission planning, the spacecraft can be stopped at any position, while the pilot maneuvers the spacecraft in attitude to find the best pointing direction for a camera or other instrument.
- In the *free-flight-abide* mode, the pilot flies the spacecraft using a joy stick and/or keyboard to control attitude, thrust, and simulation pace while abiding by all laws of physics. This mode makes interstellar travel feasible by permitting speeds

approaching light speed at a pace faster than real time. Relativistic effects are displayed and are meaningful (see "Cockpit and Window Displays - Relativistic Effects" below). This mode is also useful for simulating landings on foreign bodies such as the moon. For foreign-body landings, this mode can provide pilot training similar to Apollo simulators, in which pilots attempted to manually guide the Lunar Module from orbit to touchdown, but found they often ran out of fuel or penetrated the lunar surface. Human inadequacy made Apollo lunar descent guidance essential. Apollo lunar descent guidance will be supplied but can replaced by the user (see "User-Supplied Extensions" below).

- In the *free-flight-disregard* mode, the pilot flies the spacecraft in the same way, but the simulator disregards selected laws of physics. In this mode, the pilot can fly to a distant sun at many times the light speed.

Cockpit and Window Displays - Relativistic Effects

Cockpit displays provide the types of information available to an airplane pilot, including location, attitude, fuel level, etc. Cockpit displays also show relativistic effects on lengths, mass, and clocks. The pilot can see how time passes for those who remain on Earth compared to those aboard the simulated spacecraft.

The window display shows visible celestial bodies; the pilot can see how constellations change shape due to location in the galaxy and due to relativistic effects.

Numerous multimedia displays available with the current Distant Suns program will remain in Galaxy. These displays include background information on celestial bodies that are invoked by clicking on an object, movies depicting flybys of planets, and many others.

User-Supplied Extensions

Galaxy consists of numerous modules with clearly defined interfaces so that any module can be replaced by a later version or a version more suited to the individual needs of the user.

By replacing modules, the user can:

- Supplement the ensemble of mission trajectories with any number of custom trajectories to any location or celestial body supplied with the simulator or by the user.
- Supplement the ensemble of celestial body models with custom bodies, including their ephemerides and their surface and atmospheric properties.
- Replace hardware models with models of advanced or custom hardware. Hardware models included and subject to replacement are spacecraft translational and rotational dynamics, thrusters for translation and attitude control, reaction wheels for attitude control, and many others.
- Replace navigation, guidance, and control algorithms with advanced or custom algorithms. Algorithms included and subject to replacement are Apollo lunar descent guidance, Viking landing guidance, and many others.

Fidelity Goals

Models will be developed by numerous organizations and individuals over many years. Mission trajectories and celestial-body orbits are already modeled to high accuracy, enabling models of such accuracy to be incorporated in Galaxy at an early date, possibly within a year from project start date. Other models, such as celestial-body surfaces, need to be developed. Such surfaces can already be rendered by industrial-class workstations at frame rates that provide smooth motion. For PC-class computers, we intend to follow the same approach, i.e., rendering as fast as possible on the given computer, and accepting the resulting smoothness or lack thereof. Other long-term fidelity goals are:

- Trajectories are to be modeled to the accuracy of those supplied by JPL and other mission providers.
- Planetary motions are to be modeled to the accuracy of JPL ephemerides.
- Satellite motions are be modeled to the accuracy of JPL ephemerides, or, to the accuracy with which JPL ephemerides can be extended by numerical integration.

- Celestial-body surfaces are to be modeled to the accuracy known at the time the models are written. For landings, surface models will be extrapolated by fractal techniques to the resolution required for realistic, though artificial, rendering.

System Requirements

Here are the system requirements for running Galaxy:

1. A personal computer with an Intel 80486 or later CPU and a clock rate of 33 MHz or greater.
2. A 32-bit operating system such as Windows 95 or Windows 98 with 16 Mbyte RAM, or Windows NT version 4 with Service Pack 3 and 32 Mbyte RAM.
3. Hard disk space of 10 Mbytes.
4. A monitor with resolution of 800x600 pixels, minimum.

PROJECT EVOLUTION

The project is expected to evolve over the course of decades. In the long term, software will comprise tens of gigabytes of ephemerides; trajectories; physical models of celestial bodies and their surfaces; readers for ephemerides, trajectories, and models; navigation, guidance, and control algorithms; and rendering and display drivers. Long-term human resources may be hundreds of work years or more, depending on the initiative of contributors and on concepts for the simulator that are adopted as it evolves.

In the short term, the goal is to define a modular structure for the simulator that enables long-term evolutionary growth while introducing some basic capabilities within the first year and achieving all short-term milestones in the first three years.

Short-Term Milestones

The simulator will be developed following an evolutionary path, starting with the current version of Distant Suns and incorporating new capabilities. Tasks will be carried out concurrently, to the extent permitted by resources. Short-term milestones are:

1. Develop the capability to free fly under control of the joystick, mouse, or arrow keys.
2. Develop the capability to control viewing attitude by similar means.
3. Develop the capability to control simulation pace by similar means.
4. Develop methods for representing any trajectory or ephemeris from JPL or supplied by users in a numerical format that can be readily read and interpolated by the simulator, replacing the current Jean Meeus algorithms.
5. Develop capabilities enabling users to replace simulator modules with their own hardware modules, mission trajectories, celestial-body ephemerides, etc.
6. Adopt or develop surface and atmospheric models of all major celestial bodies in our solar system.
7. Adopt the Hipparcos star catalog to enable interstellar travel.
8. Develop the capability of landing on moon by means of Apollo guidance.
9. Develop a topographic model of the lunar surface from current data and fractal-based extensions, and develop methods for rendering the surface for display during lunar landings.

Long-Term Milestones

Long-term milestones are:

1. Model and display relativistic effects of approaching light speed.
2. Adopt or develop a model of the region near the center of the galaxy, including the dynamics of stars and black holes.
3. Adopt or develop models of quasars.
4. Extend the range of ephemerides of satellites in our solar system from current values (about +-40 years) to +-1000 years.
5. Adopt or develop models of planets in other solar systems as they are discovered.

SOFTWARE MANAGEMENT

Sources

Software modules are mostly acquired from sources other than the Galaxy staff. The intent is to have the staff supply the framework in which modules supplied by others can execute, thereby minimizing the development cost and maximizing the flexibility for incorporating updated modules as they become available.

Sources for Galaxy modules are numerous simulators existing, under development, or planned at JPL; other NASA centers; private companies in the aerospace industry; and thesis projects (see "Educational Partnerships" below.)

Ownership

Software written by the Galaxy staff is the property of Caltech/JPL. Software written by outside individuals or organizations is obtained under license with terms that may vary from case to case.

No source code is sold. Source code is made available to those outside Project Galaxy only on written authorization of its owner.

Coding Standards and Programming Languages

Galaxy coding follows standards that make it easy to acquire and replace modules, and easy to understand how the simulator works. Some of these standards are:

1. Galaxy is designed using object-oriented design methods, and modules are coded using structured-programming methods.
2. Galaxy is composed of many modules interacting according to clearly defined and documented interfaces.
3. Individual modules or groups of modules can be replaced by members of Project Galaxy in order to evolve Galaxy's capabilities for subsequent users.
4. Individual modules or groups of modules can be replaced by each user in order to fly new or proposed missions, modify or replace algorithms, extend Galaxy's capabilities, or omit undesirable features, all according to the needs of the user.
5. Programming languages in use within Galaxy include C, C++, Ada, and FORTRAN. Each module is coded for Galaxy in whichever of these languages is most appropriate for the module's function. Any module acquired from another source is translated only if it is not written in one of these languages or if there is a reason other than programming language for rewriting the module.

PROJECT MANAGEMENT

Project Galaxy is being initiated by a small number of individuals, who are either staff members of the Jet Propulsion Laboratory, prospective outside collaborators from FFRDCs such as the Draper Laboratory, or from private companies in the aerospace industry. In order for the simulator to achieve its long-term goals, it will be necessary to increase JPL involvement, and to recruit other organizations and individuals who will contribute time and software models.

In the short term, the project is being managed by consensus of the collaborators. In the long term, the plan is to have the project managed by a board of directors appointed by the collaborators or their employers.

Funding Sources

Funding from numerous sources is being sought. Sources include:

1. NASA/JPL education and outreach.
2. Department of Education.
3. National Science Foundation.
4. National Space Grant College and Fellowship program (also known as the "Space Grant Consortium").
5. Educationally oriented foundations.
6. Revenue from the sale or licensing of products. Products include CDs/DVDs to the public, and physical models developed under contract with the computer-game industry and others.

Educational Partnerships

An educational partnership is an agreement between Galaxy staff and members of a school's faculty to cooperate in the design and development of the simulator. Faculty members agree to use the evolving simulator in class and to return suggestions from themselves and their students on how Galaxy could be improved in design, capability, operation, performance, etc. Galaxy staff agree to consider all suggestions, to select and incorporate the best combination of features without regard to source, and to return new Galaxy versions to all partners as major milestones are achieved.

Partnership agreements specify neither deliverables nor schedules. Nonetheless, each partnership is expected to be interactive because both partners benefit thereby.

Thesis Opportunities

Educational partnerships with universities and colleges are likely to include thesis opportunities for graduating or postgraduate students. Thesis possibilities have been considered and viewed favorably by astrodynamics specialists from numerous universities and technical institutes. NASA's National Space Grant College and Fellowship program (also known as the "Space Grant Consortium") has been suggested as a funding source for theses.

Thesis topics include modeling black holes, such as those found at the center of many galaxies, as they consume nearby suns; modeling asteroid surfaces and rotational dynamics; modeling the surface of the moon and other celestial bodies, including fractal-based extensions to enable visualization during simulated landings; modeling piloted spacecraft such as the Apollo Lunar Module to enable displaying astronauts' field of view and the displays and controls Apollo astronauts used during lunar landings.

Thesis products are source-code modules whose interfaces conform to Galaxy specifications. Such modules enable Galaxy personnel to update or replace models as better data or improved models become available. Advanced users can also replace Galaxy-supplied models with their own models, or update models whose source code has been released to them by models' owners.

Dissemination of Products

We intend to make a portion of the simulator freely available on a publicly accessible site, such as the JPL web site. The portion available via the web is limited by the web's data-handling capabilities: It is currently infeasible to transmit tens of gigabytes of data. We also intend to make the entire simulator available to educators and the public via CDs and DVDs at nominal cost, following the model already established by similar NASA projects.

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