OpenSpace: Bringing NASA Missions to the Public

This viewpoint presents OpenSpace, an open-source astrovisualization software project designed to bridge the gap between scientific discoveries and their public dissemination. A wealth of data exists for space missions from NASA and other sources. OpenSpace brings together this data and combines it in a range of immersive settings. Through non-linear storytelling and guided exploration, interactive immersive experiences help the public to engage with advanced space mission data and models, and thus be better informed and educated about NASA missions, the solar system and outer space. We demonstrate this capability by exploring the OSIRIS-Rex mission.

The endeavors of space missions have typically been communicated and demonstrated through produced movies or animations. NASA missions, such as OSIRIS-REx, are the products of years of planning and scientific research. Explaining missions to the public in an immersive setting is challenging and has only previously been possible with produced shows for planetariums or interactively with limited mission details and external data.1,2 Our goal is to provide an interactive experience in which the public can see and experience space missions to better understand the science, the benefit to mankind, and the challenges of deep-space missions.

To achieve this, we developed the open source interactive data visualization software OpenSpace3 to visualize the entire known universe and portray our ongoing efforts to investigate the cosmos through large-scale, contextualized, multimodal astrovisualization. OpenSpace incorporates the latest techniques from visualization research and supports interactive presentation of dynamic data from observations, simulations, and space mission planning and operations.4–6 OpenSpace is capable of providing immersive experiences to multiple observers by leveraging the projection capabilities of modern planetariums.7 These immersive experiences will help better inform and educate the general public by allowing interactive exploration of NASA missions.
OpenSpace has been developed with partners from the American Museum of Natural History, Linköping University, the Scientific Computing and Imaging Institute at the University of Utah, and New York University’s Tandon School of Engineering.

**SPICE FILES AND NASA MISSIONS**

OpenSpace relies on a continuous coordinate system that enables developers to position and orient data with extreme accuracy. NASA’s Spacecraft Planet Instrument C-matrix Events (SPICE) observation geometry system for planetary science missions, for example, provides the ability to display mission planning, data acquisition, and post-mission data analysis using high-resolution data files called *kernels*. Each mission has a different set of SPICE kernels that describe the spatial and temporal aspects of the mission and its components. For example, in collaboration with the Applied Physics Laboratory, the OpenSpace team worked to visualize the Navigation and Ancillary Information Facility’s SPICE-specified instrument targeting during New Horizons’ fly-by of Pluto. SPICE’s guided visualization of planet and spacecraft orbits, instrument view frustums, and sequenced imagery over time allow for comparison of observed data with model output. While New Horizons was a specific application, the techniques apply generically across all space missions with available SPICE data. SPICE compliance accurately defines positions, orbits, trajectories, orientations, and instrument views used in data collection for Earth and planetary science, heliophysics, and astrophysics.

The ability to read SPICE kernels during mission planning and flight, including actual configurations returned by telemetry during flight, will allow for both historical reconstruction and conceptual visualization of missions within OpenSpace. To date, such full SPICE visualization has only been available in specialized mission planning software, in produced videos such as those created by NASA’s Scientific Visualization Studio, or in a limited capability with commercial software. Never before has there been an interactive, deep level of SPICE capability in planetariums or digital theaters using freely available open source software. Visualizing spacecraft attitude with respect to an observation schedule is an important link between mission operations and the science it is designed to acquire. Visualizing the engineering of how space mission science is conducted is especially valuable with respect to public education.

**DATA SOURCES**

A major product of many space missions is comprehensive planetary maps of the bodies in our solar system. Examples of this include the MESSENGER mission that mapped Mercury, the Lunar Reconnaissance Orbiter that mapped the Moon, the Mars Reconnaissance Orbiter retrieving unprecedented details of the surface of Mars, and the numerous Earth-orbiting spacecraft providing time-resolved imagery of our own planet. Many of these maps are provided as images online through the Web Map Service standard. Through this standard, images are stored in a tree with varying resolution and only images of appropriate resolution are streamed from an online server to the client application. Streaming data from a variety of online sources enables the rapid exploration of datasets from different spacecraft and also provides the ability to access near-real time imagery without the need to download entire image catalogs, thus reducing the latency between data acquisition and visualization. NASA’s Global Imagery Browse Services (GIBS) provides daily updates for many of their image sources, such as Suomi-NPP’s Visible Infrared Imaging Radiometer Suite, which provides a full global view of Earth every day depicting weather and cloud coverage. Figure 1 shows an image of the three major hurricanes that impacted the United States in 2017 and that was generated from the GIBS dataset and is being inspected by a user in real time. In addition to visible light measurements, many other mission instruments are available through this standard, for example cloud layers, ozone concentration, and temperature measurements, thus providing an immense wealth of information that can be dissected in the context of the observing spacecraft.
MULTIUSER IMMERSIVE ENVIRONMENTS

The benefits of multiuser immersive environments are deeply rooted in the human desire to share experiences and the need for a social context in which knowledge can be understood and assessed. Immersive multiuser environments come in many different flavors, with different advantages and disadvantages. The available systems range from shared VR environments using multiple head mounted displays to immersive environments such as CAVE(s) and large-scale display systems such as dome theaters. One key difference between these environments is the number of users who are tracked to provide correct first-person view of the virtual world being displayed. In multiuser head mounted systems, all users are tracked. In CAVE(s), only one person has the “correct view”. In domes on the other hand, usually no user is tracked.

Our experience shows that multiuser immersion can be facilitated in several ways without the need of tracking users. In dome theaters the size of the display and the distance to the users make it possible to generate reasonably correct views for most of the users, and the size of the environments adds the advantage of scalability in number of simultaneous users. The same argument also holds for large flat displays, such as projection walls, that support high-resolution immersive experiences such as Figure 2 shows. In these environments, user interaction is, however, often limited to one user presenting and interacting. In dome theaters, this leads to the notion of a mediated immersive experience in which a presenter, often together with a pilot, guides the audience through a demonstration. As such, this becomes a powerful tool for immersion because the story and the story teller becomes integrated components of the immersion. OpenSpace was developed primarily for dome theater immersion. It benefits greatly from the interactive capabilities of the system whereby the multiusers perceive the 3D effect of the cosmos as long as the projected image reflects camera motion. If it stops, the users suddenly experience a 2D image projected onto the dome. The 3D illusion makes this environment extremely compelling for contextualized astrovisualization.
Figure 2. Multitouch table driving a powerwall using a linked OpenSpace session such that the viewpoint on the power wall is controlled by the touch table. The imagery is the Valles Marineris of Mars obtained from orbiting satellites and streamed to OpenSpace through the Web Map Service.

Interaction can also provide a path to immersion. Multiuser interaction on touch tables is common these days and enables immersion via shared input, along with content involvement among users sharing interaction, which can sometimes result in conflict but can also lead to discussion and user engagement.

TOUCH TABLE AND PROJECTION WALL

Using large tangible touch surfaces with a multitouch navigation interface is more engaging to users than a mouse and keyboard, while also enhancing understanding of the navigation control and thus, decreasing the learning curve of the system’s user interface. Additionally, combining a multitouch interaction model together with a screen-space direct-manipulation formulation produces a user-friendly interface. We have integrated the OpenSpace user interface with a commercial multitouch display table provided by the company Interspectral AB.

Astronomical visualizations have long been an interesting application for touch-based interaction. However, due to the scale of the solar system compared to its celestial bodies, any existing object rapidly becomes exceedingly small. A direct-manipulation solution alone becomes non-trivial as it requires 3D points in the scene to constrain the manipulation and such points cannot be well tracked in empty space.

The multitouch interface is implemented in OpenSpace using the TUIO library to support a variety of multitouch devices, although we primarily targeted the multitouch table. Using this interface, the user can interact with any celestial body in the scene and traverse it through multitouch gestures. For example, Figure 1 shows interaction with satellite imagery weather data. This allows the user to intuitively zoom into the geographical area of interest.

Additionally, OpenSpace provides the capability for coupling OpenSpace sessions across devices. These could be multiple planetariums, as was done for the New Horizons encounter coupling, among others, ANMH/Hayden Planetarium with the Norrköping Visualiseringscenter C Planetarium for a cross-continent, interactive visualization and story-telling of the mission while the encounter was taking place. With the multitouch interface, we found it advantageous to couple the touch-table interface with a large tiled display to effectively contextualize NASA missions to groups of K-12 students and the general public. Figure 2 shows the table driving the tiled display wall to seamlessly control the OpenSpace session for multiple participants. A YouTube video of the interaction is available.
OSIRIS-REx Mission

OSIRIS-REx launched on 8 September 2016 at 7:05 PM EDT from Cape Canaveral. Figure 3 shows the trail of the spacecraft a few minutes after lift-off. OSIRIS-REx orbited the Sun and in September 2017, it used a gravity assist in an Earth fly-by to increase the orbital inclination to deviate from an orbit in the solar plane to an orbit matching the orbital plane of asteroid Bennu. Figure 4 shows the spacecraft’s “slingshot” to the orbital plane of Bennu.

Figure 3. OSIRIS-REx lift-off from Cape Canaveral on 8 September 2016. The location of the spacecraft at a particular time-point is determined from NASA’s Spacecraft Planet Instrument C-matrix Events data for the mission.

Figure 4. On 22 September 2017, OSIRIS-REx used Earth’s gravitational field to slingshot from the solar orbit to the orbital plane of the asteroid Bennu. Earth is the cyan trail while OSIRIS-REx is the green trail. The celestial bodies and spacecraft locations are read from NASA’s Spacecraft Planet Instrument C-matrix Events data for the OSIRIS-REx mission.
The OSIRIS-REx mission seeks to gather a sample from the surface of Bennu, a carbonaceous asteroid and return the sample to Earth. The sample may provide information on the formation of life on Earth and the Earth’s oceans, such as whether Bennu contains organics, precious metals, or water. In addition to the sample, the mission will map the asteroid and use its advanced instruments to measure the Yarkovsky effect (non-gravitational forces which cause orbital deviation) as well as compare close-range observations with Earth-based observations.

By using NASA’s SPICE kernels for this mission, the reconnaissance campaign mapping the asteroid can be visualized and the instrument activation highlighted as shown in Figure 5. By using the actual mission planning data contained in the NASA SPICE event file, which contains the mission timeline, a visualization and contextualization of the mission is accomplished. This can be shown in an immersive environment to describe the mission and its scientific actions to better inform and educate the public.

Figure 5. OSIRIS-REx maps Bennu on 25 May 2019 before obtaining the samples. The spacecraft and Bennu are modeled as geometry. Once the actual images are sent back to Earth, the mapping would appear as textures on the asteroid surface. The spatial/temporal locations of the asteroid, spacecraft, and its instruments are read from NASA’s Spacecraft Planet Instrument C-matrix Events data for the mission.

CONCLUSION

We have described OpenSpace, a software for the visualization and demonstration of NASA missions. The ability to interactively display and communicate missions during mission planning and/or mission activity and/or post-mission data analysis is a powerful method for public education. One key component is the ability to visualize the data acquisition operations from the viewpoint of the spacecraft using SPICE data. Immersive environments add to the realism of presenting NASA missions and a variety of immersive devices are supported; from display walls to touch tables to multiuser immersive theaters such as planetariums. We believe extensions to educate the public on space science, such as explaining the importance of space weather, will result in better public awareness and support of NASA missions. Our viewpoint is that diverse information needs to be aggregated and made available to visualization software that can integrate multiple sources, allowing a coherent visual communication to a wide variety of audiences and space science consumers. This requires the flexibility of a number of delivery and interaction mechanisms from the software.
REFERENCES


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