OPENSPACE: DEVELOPMENT UPDATES AND EDUCATION APPLICATIONS. M. E. Gemma[1,2], C. Roe[1], C. Emmart[1], V. Trakinski[1], R. L. Smith[4,5,6], M. Acinapura[1], B. Abbott[1], D. S. Ebel[1,2,3], and R. Kinzler[1]. [1]American Museum of Natural History, New York, NY 10024, [2]Department of Earth and Environmental Sciences, Columbia University, New York, NY, 10027, [3]Graduate Center of CUNY, New York, NY, [4]NC Museum of Natural Sciences, Raleigh, NC 27601, [5]Appalachian State University, Boone, NC 28608, [6]UNC Chapel Hill, NC 27599.

Introduction: OpenSpace [1] is an open source interactive data visualization software designed to visualize the entire known universe and portray our ongoing efforts to investigate the cosmos. OpenSpace supports interactive presentation of dynamic data from observations, simulations, as well as space mission planning and operations, and allows visualization at the outcrop level on extraterrestrial bodies. The software works on multiple operating systems (Windows, Mac, Linux) with an extensible architecture powering high-resolution tiled displays and planetarium domes, making use of the latest graphic card technologies for rapid data throughput. In addition, OpenSpace enables simultaneous connections across the globe creating opportunity for shared presentations among audiences worldwide.

Invitation: Several participants in the OpenSpace project are present at LPSC 2020. We invite you to:

1) Visit the OpenSpace booth in the exhibitions area for a demonstration any time this week.

2) Let us know what you want from the project.

Scientists are welcome to team with programmers at their home institutions to develop modules for OpenSpace. A module could include, e.g., a visualization of part or all of an individual mission, including spacecraft model and SPICE navigation kernels and visualization of science results.

Content Development: The last year has seen an increase in the number of interactive scenes of visualized NASA data available in OpenSpace to 17, with the goal to reach 20 scenes by the end of this year. Non-technical story guides and user-friendly presentation buttons that align with content points have also been introduced, and can be accessed on a mobile device. The creation of new content continues to depend on collaboration with NASA agencies and infrastructure along with outside scientists and agencies. New scenes include:

Apollo 8, 11, and 17: Models and trajectories for these missions are included, as well as the Apollo 11 and 17 landing sites. The Apollo 8 and 11 orbit trajectories were supplied by NASA GSFC SVS Media Specialist Ernest T. Wright. Imagery of the Apollo 8 Command Module interior was created from the Smithsonian National Air and Space Museum's scan of Apollo 11's Columbia Command Module (**Fig. 1**). The 3D Lunar Excursion Module model for Apollo 11 and 17 was created using photogrammetry of LM-2, on display at the Smithsonian National Air and Space Museum. Photogrammetry of boulders from Apollo 17 Haselblad photography has also been implemented, along with USGS/German Aerospace Center visualizations of Apollo 17 rover traverses.

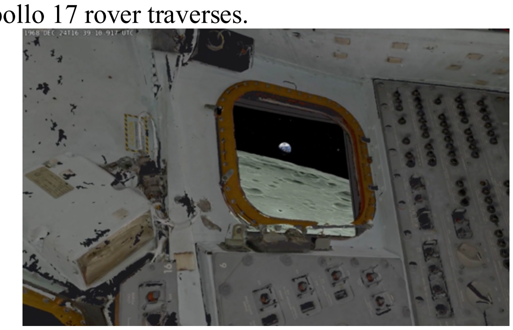

Fig. 1: Earthrise from the interior of the Apollo 8 crew module, December 24, 1968. Using SPICE kernel reconstructions based on DSN telemetry.

InSight Lander: This scene contains a model of the InSight lander and its trajectory during Martian atmospheric entry and landing on November 26, 2018. The model changes throughout the different phases of the landing, e.g. during the separation of the heat shield and the deployment of the parachute. Collaborator NASA Eyes on the Solar System provided data and models.

Gaia: ESA's Gaia mission data was added using a new and experimental multiscale renderer. The dataset is automatically synchronized at startup and contains over 7 million stars and their radial velocities.

In addition to new scenes, existing scenes have been updated to include new content, such as:

Volumetric Milky Way: Collaboration between the National Astronomical Observatory of Japan and the AMNH space show team resulted in a constrained simulation of the Milky Way that conforms to AMNH's Digital Universe (DU) dataset and new Gaia results.

Space Debris: More efficient rendering methods for small objects have allowed visualization of the trajectories and positions of all space debris objects as reported on the Celestrak webpage [2].

Mars Surface: The Mars surface scene was enhanced with two new map layers: local HiRISE data patches, and a blended CTX map from CalTech's Jay Dickson.

Saturnian Moons: Hyperion and Mimas were added to the Saturnian system in all scenes.

Satellites: Trails of Pioneer 11 and 12 were added, and the Pioneer model was improved. Trajectories of the Swift-Tuttle comet, Tesla Roadster, and 'Oumuamua are optional content that can be added to any scene.

Earth: In addition to the existing daily atmospheric layer in OpenSpace, oceanographic datasets such as sea surface temperature (**Fig. 2**) have been added.

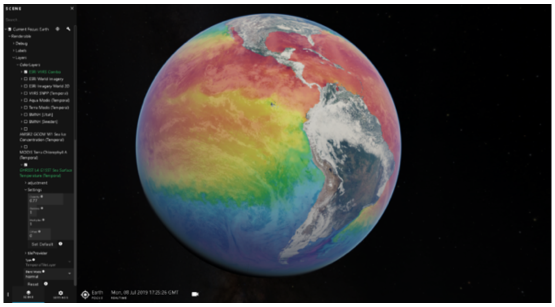

Fig. 2: Near Real Time Earth Compositing: NASA Global Imagery Browse Service showing SNPP VIIRS True Color daily mosaic with international Group for High Resolution Sea Surface Temperature (GHRSST).

Software Development: As in previous years, software engineers and graduate research associates at AMNH, Linköping University, New York University Tandon School of Engineering, and the University of Utah Scientific Computing and Imaging Institute have collaboratively contributed to a workflow that fosters near real-time, memory-efficient algorithms to handle data intensive tasks, multi-modal rendering, integration of new data sets, and hardening of the software code.

During the last year, three significant updates of the OpenSpace software were published, the most recent being Beta-5 (v0.15.0), released on September 17, 2019. Each improved software stability and usability, particularly for older hardware. Releases also included high priority technical improvement such as an enhanced Graphical User Interface, the means to control OpenSpace on a handheld device for easier presentation, and increased documentation. Major new features include:

OpenSpace Launcher: This new start-up option allows users to select their screen output and scene, negating the need to edit a text file to do so.

Session Recording: This feature enables the recording of camera movements, state changes, time, speed, and user interface interactions which can then be played back or shared between computers. This is done from a recording menu that allows users to create, play, and stop the recording, as well as stream live to YouTube.

Slides Menu: This menu allows users to show online and downloaded image files within OpenSpace. This has been be used to show historic mission images within an OpenSpace visualization of that mission.

Anchor and Aim: This feature enhances the previous Focus Node. It is still possible to focus the camera on a single object and have all camera movements occur relative to that object, but it is now also possible to anchor on one object while aiming at another, which stays fixed on the screen. This presents a view of the objects in relation to each other, affording cinematic results.

Search: Scene and settings menu search bar functionality were significantly improved, easing usage.

Education: To date, OpenSpace has supported hundreds of interns, from high school to post-baccalaureate, at partnering informal science institutions (ISIs). Interns learn vital STEM skills and knowledge, including computer programming, astrophysics, planetary science, and science communication. OpenSpace lends itself well to student involvement in the development of visual renderings, as well as the production of interactive "tours" for various audiences. Since 2011, AMNH has hosted 17 high academic achieving seniors from Bergen County Academies High School in Hackensack, NJ. In 2019, four BCA students have assisted data entry into OpenSpace in four areas: 1. MRO CTX stereo terrain processing using ASP, ISIS3 and GDAL, 2) Adding existing NAIF SPICE for all published missions, 3) Adding additional solar system bodies from JPL Horizons and Keplerian orbital definitions, and 4) Adapting existing 3D models of spacecraft and constructing additional ones. OpenSpace has also been used to interactively teach planetary science to high school students through AMNH's After School Program.

Public Outreach: OpenSpace is a robust tool to communicate NASA science results and mission activities to public audiences. Work within OpenSpace has been shared via public programs at AMNH and partner ISIs. In particular, the 50^{th} anniversary of the Apollo 11 moon landing was an ideal time to demonstrate the many capabilities of OpenSpace. At AMNH's SpaceFest, attendees able to see and experience the same surroundings as the Apollo 11 astronauts. OpenSpace is particularly effective as a science communication tool, as it can be used to visually answer questions regarding celestial phenomena at all scales of the universe.

Discussion: OpenSpace allows visualization of scientifically important data, as well as the technology, engineering, and math of space missions. It enables science communicators to visually explain how we engage in discovery across the solar system and beyond, accomplished in part by accurate rendering of image pointing and regions of acquisition projected from instruments as view frustums in OpenSpace. Navigation kernels and the DU allow time- and space-accurate rendering of spacecraft paths throughout the solar system. The open source nature of the software encourages module development by collaborators beyond the existing team. Academic publications about OpenSpace are at [3].

References: [1] http://openspaceproject.com/,
[2] https://celestrak.com/,
[3] https://www.openspaceproject.com/academia/

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