Gaia Journeys: A Museum-based Immersive Performance Exploration of the Earth

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Introduction

Digital globe software is commonly used today by experts and novices alike for the exploration of geospatial data. Although Al Gore's original vision of a "Digital Earth" imagines a young child viewing the virtual world via head-mounted goggles (Gore 1998), most users still interact with the software on a flat computer monitor. Little work has been done by virtual globe vendors in the realm of virtual reality, where a user is immersed within an interactive, multi-sensory virtual environment.

Recently a new class of publicly accessible virtual reality theaters has opened in museums and science centers that can bridge this gap.[1] The number of digital video "fulldome" planetariums (Lantz 2003) have grown explosively (Lantz 2006), with more than 270 in operation worldwide since the start of the decade (Neafus, Bruno, & Petersen 2005). For this expanding market, multiple vendors now sell astronomy simulation software which re-create digital versions of not just a traditional planetarium's night sky view, but also the rest of the known universe. In addition to running familiar planetarium shows, these immersive theaters are virtual reality spaces suitable for education (Yu 2005), displaying content from other scientific and cultural disciplines (Matthews 2005), data visualization (Fluke & Bourke 2005; Emmart 2005), and tele-collaboration (Emmart 2005).

In addition to the latest astronomical catalogs, the virtual universe software often contain high fidelity recreations of the Earth using imagery like NASA's Blue Marble (Stökli et al. 2000) textured onto digital elevation maps. The geospatial features of the digital universe programs lag behind more well-known digital globes, mainly because the focus of planetariums remain away from the Earth's surface. Yet digital planetariums offer their audiences some unique benefits. Their status as theater spaces means large groups can listen to a lecture or participate in a discussion. They can have extremely high resolutions: the largest theaters have multiple edge-blended projectors which tile the domed display surface with tens of millions of pixels. They are also completely immersive: instead of viewing the data representation through the narrow window of a computer monitor, the audience member is surrounded by the data inside the dome. If a digital globe is the most intuitive way to *view* Earth data, a video fulldome planetarium may be the best way for a large audience to *experience* a digital globe.[2]

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1 A second type of spherical display increasingly found in museums show imagery on the outside of a sphere, e.g., NOAA's Science on a Sphere (Albers et al. 2005) and the Naturalis Museum's Globe4D (Companje et al. 2006). Because the sphere is fixed in size, applications running on these systems cannot zoom into the data in the same way as other geobrowser software.

2 "Space-to-Face," a digital globe application, was created by SGI in 1996 (Aubin 2006) to run in their edge-blended Reality Centers (Helsel 2000) and CAVEs (Cruz-Neira et al. 1992). However these immersive precursors to digital planetariums have remained too expensive to be found outside of academic research labs and industry. Digital planetariums can also be expensive to build, but they can fit many more people than a CAVE, are growing exponentially in number, and are generally widely accessible by the public.

Musical Performance in Planetariums

Planetariums have a long history as sites of experimentation with audio and visuals to create new multimedia experiences. Jordan Belson and Henry Jacobs collaborated on roughly one hundred *Vortex* concerts in 1957-1959 at the Morrison Planetarium in San Francisco. Using the planetarium's star projector along with a dozen other specialized devices including interference projectors, film loops, and kaleidoscopes, Belson and Jacobs combined experimental film projected onto the overhead dome with spatialized electronic music (Youngblood 1970, pp. 388-391; Moritz 1999). The Laserium concerts were pioneered by Ivan Dryer and began at Griffith Observatory in Los Angeles on November 19, 1973 (Laserium 1998). Although Laserium became a popular mainstay of planetarium programming involving pre-recorded music for decades, experiments with live musicians continued over the years (e.g., Kinsella 1984).

Given the impressive display capabilities of fulldome theaters and the new class of astronomy simulation software, it was inevitable that the next incarnation of the planetarium music show would involve these new digital technologies. The planetarium program team at the Denver Museum of Nature & Science (DMNS) had long been open to this type of artistic and collaborative experimentation. When the opportunity came, the group enthusiastically jumped at the chance to work closely with musician (and co-author) Williams to create four *Gaia Journeys* concerts for a domed environment. These live musical performances combined spatialized live and pre-recorded music with immersive visuals. The concerts took place 15-18 February, 2007 in DMNS' Gates Planetarium, a digital fulldome theater equipped with stadium seating, automated lighting, a 16.1 channel sound system, and eleven Barco Executive R6 DLP projectors sending more than ten million pixels of content onto a 16.9 meter diameter, 25° tilted dome (Neafus & Yu 2007; Figure 1).

Artistic Goals

The ability to "fly" a virtual camera over a richly detailed recreation of the Earth's surface was one of the inspirations for the design of the digital Gates Planetarium. Showing such visuals within a high resolution immersive display in fact may be the closest approximation to space travel that most people will ever get to experience. It was this desire to show the Earth as astronauts saw it from low Earth orbit that Williams wanted to replicate. Beginning with Yuri Gagarin (Krasnaya Zvezda 1961), returning astronauts and cosmonauts have spoken of the startling beauty of the Earth from space. They have remarked on the border-less view of the Earth from orbit, with the implied unity of the world and the people living on its surface. The astronauts often returned with the heightened need to protect and preserve humanity's home planet (e.g., Kelley 1988). Given the growing environmental and social problems that demand concerted global action, Williams wanted to present an artistic program that could raise a sense of awareness of the Earth similar to that of returning astronauts.

A second goal was simply to present to audiences scenes of beauty. Views of the planet from low Earth orbit often show startling yet beautiful contrasts in colors and shapes. Many of the scenes in *Gaia Journeys* were tailored around flights over carefully selected regions: the near-regular geometry of snow-peaked mountains in the Cascades and Himalayas, the stark desert-scapes of the Sahara, and the brilliant azure waters of the Caribbean. Each *Gaia Journeys* show lasted 50 minutes. Descents to the surface of the Earth were added to break up the space-based scenes, which made up a majority of the flight. At these Earth-based locations, spherical panorama photography would fade up to provide vivid views of places up close. These ground-based images were taken at locations world-wide by co-author Downing.

Virtual Simulation Software

The real-time virtual simulation software running on the Gates Planetarium's 12-node visualization cluster (consisting of Hewlett-Packard xw8400 workstations with Intel Xeon Quad-Core processors and Nvidia Quadro FX 5500 GPUs) is SCISS AB's Uniview, with three-dimensional positioning of stars and galaxies from the American Museum of Natural History's Digital Universe database (Abbott 2006). Real-time simulations are often built with scenegraphs: spatial data structures that organize everything within the scene, including model geometry, textures, and light sources (e.g., Akenine-Möller & Haines 2002; pp. 355-357). Scenegraphs inherently have near- and far-clipping limits, which determine how large of a volume of space can be rendered. SCISS gets around this problem by constructing Uniview using a set of nested scenegraphs (which they term "ScaleGraphs") that allow for smooth transitions from the largest to the smallest scales within the simulation (Klashed et al. 2004). Although the majority of the camera flightpaths were limited to around and on the surface of the Earth, *Gaia Journeys* does begin and end in deep space. The finale involves a long camera pullout away from the Earth, and eventually out of the Milky Way Galaxy, which the ScaleGraph transitions allowed us to perform seamlessly.

High resolution geometry and texture paging of the surface is enabled using the Realtime Optimally Adapting Meshes (ROAM) Version 2, an adaptive quad-tree algorithm dynamically paging datasets from disk (Duchaineau 2003) with asynchronous tile loading (Persson 2005). The Earth textures originate from a 43 200×21 600 map (0.93 km resolution at the equator) with 24 bits per texel (Visible Earth 2002; Stökli et al. 2000), while the height map has a size of 16 384×8192 (2.45 km resolution at the equator; Space-Graphics.com 2005) at 8 bits resolution.

SCISS provided a preliminary version of a panoramic photography loader soon after we had started designing the flightpaths and visuals for the show. This expanded capability allowed us to incorporate co-author Downing's panoramic photographs into the presentation. Each panorama is loaded in as a single equirectangular texture that is then mapped to a spherical geometry. The geometry is placed on the surface of the virtual Earth at a user-defined latitude-longitude coordinate pair (which we have tried to determine as accurately as possible for each of the locations). The maximum texture size is fixed by the GPU, which in this case result in 4096×2048 image maps.

Uniview offers several navigation modes which were utilized by author Yu to choreograph the live navigation each night. *Free flight* gives the user control over camera direction and velocity. However it was used only for a beginning sequence involving a flight from the Moon to the Earth. Most of the near Earth motions were accomplished with the *orbital flight* mode, with the camera locked to the planet, and the user controlling the direction of the camera movement, the radial distance from the center of the Earth, and the pointing of the camera. Uniview allows camera position and orientation to be saved as "bookmarks," and a number of scene transitions utilized either automated camera flights or "jump cuts" (with a fade-to-black followed by a fade-up-from-black) to these bookmarks. After the transition was completed, camera control was returned to the user for continuing live navigation. Also possible were both smooth flight and jump cut transitions down into a panorama geometry. The camera would then be panned around to allow the audience to view different features of the scene.

Photographic Panoramas

The eighteen photographic panoramas used for *Gaia Journeys* were taken by Downing between 1999 and 2006 on various photography assignments, for clients ranging from UNESCO to Intel Corp. They were created with a number of different cameras, including the Nikon CoolPix 990 and the Canon 5D, lenses ranging from 20 mm to 35 mm, and a specialized panoramic photography head by either Kaidan or Manfrotto. The lens and resolution resulted in final panoramas of different sizes: a 20 mm lens on a 5D required 20 exposures, giving an equirectangular panorama roughly 16 000×8000 pixels in size, while a 35 mm lens required 38 images and yielded a 36 000×18 000 pixel panorama. The individual images were stitched together using Panorama Tools and RealViz's Stitcher software. Nearly full resolution cubic environment map versions of these images were originally used at DMNS for a series of panorama travelogue lectures by Downing in early 2005 and 2006 (Bienias 2005). They were converted to the equirectangular spherical maps necessary for Uniview using Click Here Design's CubicConverter.

The eighteen panoramas used in *Gaia Journeys* included ones showing: the al Dier monastery and siq in the city of Petra in Jordan; the Loggia dei Lanzi in Florence; a Navona Square cathedral in Rome; Red Square, Moscow; Sedona, Arizona; Boulder, Colorado; the Burning Man Festival in Black Rock City, Nevada; Yosemite Park, California; Tikal National Park, Guatemala; temples and tombs at Qutib Minar in Delhi, India; and the harbor of Sydney, Australia.

The Musical Performance

The musical performance consisted of a live improvisational performance by Williams on his violin, with a stereo pickup sent to his Apple MacBook laptop where it could be modified by additional effects such as echoes and delays before being routed to the mixing board. A backing track composed by Williams was played as an audio stream from his laptop. Finally a Nord Lead keyboard was used to provide additional effects.

Williams combines live violin with composed "space music" style tracks, with influences from Detroit techno, acid house, European progressive, trance, reggae, and dub. His music has been described as "multilayered," "lush" (Eaton 2004), as well as "ethereal" and "eclectic" (Moore 2005). Repetitive beats and electronic textures are combined with long delays applied to the live violin. Although trained classically since the age of seven, Williams' current approach to the violin is more improvisational and very different from the instrument's western classical roots. His current compositional and production approach uses electronic and non-traditional effects such as delay and reverb in the sound.

Gaia Journeys was broken into four sections, with the aforementioned musical style used for the first, second, and fourth movements. The camera was either in Earth orbit or in deep space, and constantly in motion, with no specific ties to a particular geographic location. The first movement was an Arrival from Deep Space, with the camera making a close passage by the nighttime side of the Moon before traveling to the Earth with a free flight back and forth between the lit and shadowed sides. The second movement was a low-orbital Hover Above the Earth, with the camera staying 300-500 km above the surface. Slow graceful movements simulating orbital flight were made across the Pacific Northwest, the Amazon Basin, the Sahara Desert and northern Africa, and the Himalayas, with fade-to-black transitions between each one. The Finale started with a slow approach to the March 29, 2006 total solar eclipse across northern Africa, Mediterranean Sea, and Turkey. Faster-paced orbital flights followed: first over Asia starting at the Caspian Sea and moving east and south to Australia with the camera pirouetting away from the Earth above the Great Barrier Reef; and then the Western Hemisphere following the Americas from the Arctic Circle down past Tierra del Fuego and into Antarctica. This final sequence ended with the camera moving quickly away from the ground, resulting in a receding Earth that emulated the look of the Apollo astronaut photographs of the Earth from the Moon. The flight continued onto Mars with the camera passing by its small moon Phobos, and then skimming the Martian lowlands. The final minutes of the program ended with a pullout away from the Solar System, then away from the local stellar neighborhood, and finally out of the Milky Way Galaxy completely.

The third movement was the longest of the four, and was distinct from the others. Instead of staying in space, the camera alternated between low Earth orbit transitions and plunging down to the ground to tour spherical panoramas on four continents. The goal of the movement would be to fully immerse the audience at each location, both geographically and culturally, by sound as well as sight. The music would tie into each location's environment and spirit. As a result, the backing track as well as improvised keyboards and violin contained a series of culture-specific sequences linked together and tightly timed to each geographic location. For example, a visit to Petra in Jordan was scored with Middle Eastern-influenced music, which utilized instrument samples of bouzouki, clarinets, and Saz, as well as vocal singers from the region, while the violin was played in a Middle Eastern pentatonic scale. A subsequent visit to India was matched with a different musical style which implemented uniquely Indian instruments, such as the tabla and sitar, and Indian vocal melodies.

Although the final soundscape contained both pre-recorded and live elements, the pairing with the dome visuals was tightly choreographed. The timings for the transition points between the four broad movements of the concert, as well as critical intra-movement scene and mood transitions, were determined well ahead of time. Certain elements of the flightpath were improvised resulting in a unique performance for each night. However the backing track provided fixed lengths for each of the movements, and hence the entire show.

Audio Mixing

The domed environment presented both challenges and opportunities for the audio engineers (led by co-author Gaston). The sixteen Meyer Sound main speakers are symmetrically spaced on the outside of the perforated aluminum dome: six are along the bottom front half of the dome, seven in a second surround ring higher up, and three along the front-to-rear meridian providing center narration and verticality (Figure 2). The positioning of all audience members with respect to the tilted dome meant that viewers in the front will hear something different from viewers in the rear of the theater. Therefore, the goal was to keep the violin placed "low and center" in the theater, since Williams' performance took place on the stage at the bottom of the theater. During rehearsals, the audio team felt that trying to "spread the violin out" would yield too much of a disconnect visually: having the sound of the violin too far away from the artist's position on the floor would be too distracting from the point of view of a person sitting close to the stage. However, keyboards, effects, and the backing track could be panned out slightly to the rest of the speakers, giving more of an ambient, enveloping feel. It was necessary to walk around the theater and see how the mix would be perceived from different seats, and in our final mix most of the sound was placed toward the front, with minimal use of the rear speakers.

Acoustically the seating area in the theater is very absorptive, while the perforated dome is semi-transparent to sound, and has a more reflective or "live" surface. For speaking and intelligibility on the ground, the theater is very good, but for sounds transmitted from speakers located behind the dome, some localization (the ability to accurately point out where a sound is coming from) problems occur. High frequencies tend to bounce around, so that sounds intended to come from the rear can appear to have frontal orientation for people seated closer to the forward dome surface. Achieving phantom images between two speakers is difficult because of this phenomenon, and due to slight variations between each speaker's frequency response and its behavior in the dome (impulse response).

Overcoming these obstacles was accomplished by creating a conservative mix, which was possible because of the nature of the music. The reverb from Williams' effects processors served to create an enveloping feel, and pinpoint accuracy of images was not necessary in this performance. There are solutions on the horizon which will help to reign in some of the inconsistencies of the dome, including a product by Trinnov Audio which our team is currently researching and which shows much promise for a future follow-up event.

Two Yamaha 02R digital mixers were utilized: one on the stage that Williams used to blend the sounds to create his desired musical expression with an eight channel "performance mix" (keyboards, violin, computer and effects, all in stereo); the second board was used by the house engineer to receive these channels (via the auxiliary sends, which were routed internally to receive direct outs from each channel) to the planetarium's Meyer speaker array using a "5.1" speaker mapping, adapted for the theater's 16 surround speakers. This second board also served as the feed for an Alesis HD-24 hard disk recorder.

Although the dome is capable of 16.1 channels of audio (sometimes referred to as "16.4:" 16 main speakers and an LFE channel assigned to the four Bag End subwoofers), the audio team settled on using a 5.1 speaker mapping provided by Lake Technology's Huron20 3D audio spatialization software. The software allowed Left, Center, Right, Left Surround, Right Surround and LFE channels to be assigned to subsets of the 16 main speakers in the dome. This allowed the team to use the Yamaha 02R to do simple 5.1 panning with each stereo channel from Williams' setup. The violin was assigned to Center, and also to Left and Right at a slightly lower level. This helped us achieve our desired goal of localization of sound and visual with respect to Williams' position on the stage. The keyboard, effects, and backing track were assigned primarily to Left and Right, and at a minimal level to Left Surround and Right Surround.

Audience Evaluations

Audience feedback came in the form of a standardized survey sheet which the Adult Programs division at DMNS uses for all of its public events. The returned surveys were only from those audience members who chose to pick up the sheet at the end of the program, and fill out the survey on the spot, or who decided to fill it out at home and remembered to mail back the completed form to DMNS. Based on an analysis of a preliminary subset of 36 of the forms returned, the program was well-liked by our visitors: *Gaia Journeys* averaged 4.0 on a 5-point scale, with 70% of the reported audience reaction giving either a 4 or 5 score. This is higher compared to other new and experimental programs, but is lower than the average score of 4.6 for *all* DMNS visitor programs. However this latter number is heavily weighted by the traditional programming norm that is expected by visitors who regularly attend science lectures at DMNS. The majority of new and infrequent visitors (those who attended fewer than three Adult Programs events in the past two years) gave *Gaia Journeys* its highest marks, and stated that they would definitely come back for more.

Of the responses to the question of what was most enjoyable about the program, one third of the audience responses specified only the space and/or panoramic visuals. Another one third cited the entire experience: both the visual and audio integrated as a cohesive whole. When asked what they would like to see changed, one quarter of the respondents found nothing wrong or would like to see more of the same. We found it encouraging that the remaining complaints (e.g., not having adequate information about the visuals, issues related to distractions or the viewing environment) could be mitigated in future performances.

The DMNS audience surveys were not designed to quantify how specific aspects of the experience unique to *Gaia Journeys* affected the audience. Yet the general comments suggest that for many, the combination of the audio with the photo-realistic visuals within the immersive display made for a dramatic, exhilarating experience. A more carefully designed survey should help measure affective responses for a future iteration of *Gaia Journeys*.

Beyond *Gaia Journeys*

Judging from the audience reactions and the positive feedback from the production team, a repeat performance of or even a sequel to *Gaia Journeys* is likely. The program was recorded on high-definition (HD) video by three different videographers. The wealth of visuals will allow the show to be reformatted for other media and venues, such as high-definition television and home video release.

The success of the event within a digital planetarium suggests the potent nature of such immersive theaters. Research indicates that the impact of virtual reality may go well beyond simply breath-taking visuals. The advantages of immersive virtual reality technologies in education have long been recognized by researchers (e.g., Dede et al. 1996, Salzman et al. 1998). Digital planetarium displays have by their nature: wide field-of-views, high resolutions (typically many times that of an HD frame), and imposing display sizes. These environmental factors can lead to an increase in the psychological sense of presence (Taylor 1997, Lin et al. 2002), while well constructed virtual reality experiences can increase audience engagement and motivation (Dede et al. 1996).

Digital planetariums also have benefits from their scale and heritage. The largest facilities (>25 meters in diameter) have audience capacities of 400-500 people. They are often the result of renovations of pre-existing facilities at museums and science centers, and as a result are publicly accessible and have large built-in audiences. In a year's span of time ending March 2007, the 1500 planetariums in the United States (traditional and digital) had a total attendance of 30 million visitors, with worldwide attendance (spread out over 3200 facilities) close to 110 million (Petersen 2007). Because the number of digital planetariums is expected to continue increasing in coming years and the medium may merge with large format film as it goes digital (Lantz 2006), the impact by this new technological venue on informal public education can be enormous.

A number of institutions, including DMNS, are interested in showing non-astronomical science content to their audiences. If digital globe vendors decide to develop for the multi-channel graphics display systems and fisheye projections commonly found in fulldome planetariums, it is likely that their products will be embraced by this informal learning community. Solving problems in climate change, population growth, resource allocation, and emergent diseases require both informed policymakers and a well-educated public. Digital globe software can organize and help us understand these complex topics. The fulldome theater may be the best classroom environment to showcase such tools.

Summary

Gaia Journeys is a collaborative multimedia musical and virtual reality art performance conceived by author Williams, with the aid of staff at the Denver Museum of Nature & Science, and using imagery by author Downing. Inspired by astronauts who spoke of seeing a border-less world from orbit, *Gaia Journeys*' chief goal was to deliver this experience to museum audiences by surrounding them with photo-realistic virtual depictions of the globe from near Earth orbit within an immersive virtual environment tightly choreographed to live musical accompaniment. *Gaia Journeys* took place in the high resolution digital "fulldome" Gates Planetarium, where audiences were taken on an audiovisual virtual exploration of the Earth from orbit as astronauts would see it, as well as from the surface via a set of spherical panoramic photography. During the performance, Williams played the violin and keyboards, enhancing a previously recorded backing track, while the virtual environment from SCISS AB's Uniview software was navigated live. Uniview allowed the audience to simulate orbital flight with high resolution imagery and digital elevation maps of the virtual globe paging in dynamically. During excursions to specific surface locations on the Earth, eighteen separate high resolution digitally-stitched spherical panoramic photos were faded in and panned across. The eight tracks of audio were 3D spatialized to the 16.1 sound system of the Gates Planetarium using a Lake Huron DSP platform, providing an immersive sound experience to match the visuals.

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Captions

Figure 1: A profile view of the Gates Planetarium, a 16.9 meter diameter, 25° tilted digital fulldome theater. The eleven projectors are arrayed below the bottom edge of the perforated aluminum dome, while the 16 speakers are positioned outside. The walls surrounding the dome are acoustically baffled.

Figure 2: Main speaker placements in the Gates Planetarium: (Left) from behind looking to the front; (Right) from the left side looking in.

Figure 3: A *Gaia Journeys* performance in the Gates Planetarium with Williams on violin; the virtual camera is over the Himalayas and headed southeast toward the joining of the Ganges and Brahmaputra Rivers.

Figure 4: A spherical panorama by Greg Downing of the Mayan pyramids in Tikal, Guatemala shown during a *Gaia Journeys* performance.