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ARTICLE

Planetarium of the Future

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Abstract Over the last decade, hundreds of planetariums worldwide have adopted digital "fulldome" projection as their primary projection and presentation medium. This trend has far-reaching potential for science centers. Digital planetarium capabilities extend educational and cultural programming far beyond night-sky astronomy. These "digital domes" are, in essence, immersive visualization environments capable of supporting art and live performances and reproducing archeological sites, as well as journeying audiences through the local cluster of galaxies. Their real-time and rapid-update capabilities set them apart from giant screen cinemas. Studies suggest that well-designed immersive mediums communicate concepts better, create a greater interest in learning, and are more effective than a movie screen or television at conveying scientific concepts. This article introduces digital domes as a new medium, then discusses ways in which the potential of these environments might be tapped in the future to meet scientific and cultural needs in museums of all types.

INTRODUCTION

Planetariums are in the midst of an unprecedented transformation that is not only changing the underlying technology used to deliver planetarium programming, but also promises to radically expand the role of the planetarium in the modern museum and science center. Over the past decade, digital planetariums, also known as fulldome theaters, have rapidly grown in number (see Lantz 2002; Yu 2005; Wyatt 2005). There are now nearly 800 digital dome screens, ranging from small inflatable mobile domes to the largest projection domes in the world (Lantz 2002; Yu 2005; Wyatt 2005; Lochness Productions 2011). These digital theaters can now be found in some 20 percent of all planetariums worldwide.

Fulldome theaters project seamless, high resolution digital images over a near-hemispheric screen to deliver a visually immersive field-of-view to audiences. Nearly all of these systems allow the playback of immersive programs—immersive cinema, essentially—produced in a standard dome master format. In addition, nearly every digital planetarium is also capable of real-time, random-access navigation through extensive three-dimensional astronomical datasets and simulations using a joystick or mouse. These real-time capabilities augment traditional planetarium functions based on naked-sky astronomy. Fulldome theaters additionally allow intergalactic fly-through demonstrations of scientifically accurate models of the universe.

Although most fulldome theaters are designed as digital planetariums with a mission to deliver informal astronomy education programming, digital planetariums are, in fact, general-purpose group immersive visualization environments capable of supporting a wide range of programming types. This article introduces digital domes as a new medium, then discusses ways in which the potential of these environments might be tapped in the future to meet scientific and cultural needs in museums of all types.

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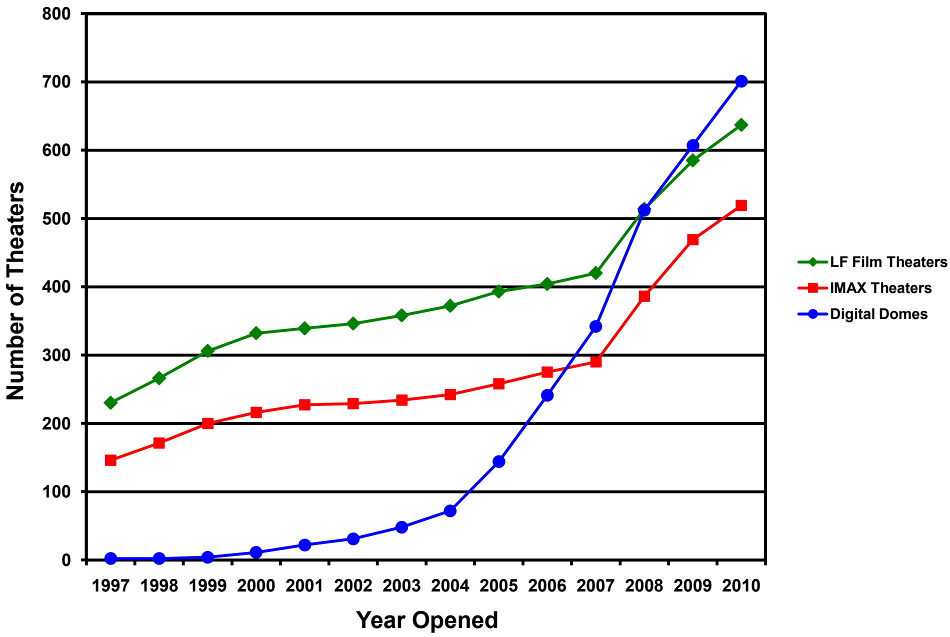

Figure 1. Number of digital domes, IMAX branded theaters, and all large-format film theaters combined (Lochness Productions 2011; LFX Database 2011; Lantz and Thompson 2003).

Current trends suggest that digital domes may emerge as a key component in a future digital infrastructure designed to aggregate and disseminate experiential data, information, knowledge, simulations, art, and performances across a range of disciplines in science, art, and the humanities. Such an infrastructure could lead to fundamental changes in how museums curate, exchange, and disseminate their assets to the public. Digital domes are a blend of art and science, which encourages crossover between these differentiated "value spheres" of human activity, expanding the palette of the artist while fostering deeper assimilation of new scientific understandings into visitors' personal cosmologies or worldviews.

BRIEF HISTORY OF DIGITAL DOMES

The classic planetarium, introduced in 1923 by Carl Zeiss Company, was designed to produce a scientifically accurate diorama of the night sky for teaching naked-eye astronomy. Nearly all planetariums employ a near-hemispheric dome screen onto which the celestial sphere is projected using an astronomical simulator or "starball." While ideally suited for reproducing the night sky, early planetariums could also be used for other forms of immersive storytelling. In the 1940s, for instance, Dinsmore Alter, director of the Griffith Observatory in Los Angeles, produced a simulated moon mission called "A Trip to the Moon," using special effects projectors that imaged approaching and landing on the moon (Hansen, Wang, and Cook 2011).

After the Soviet Union launched Sputnik in October 1957, the Space Race brought recognition that the planetarium could be a space-related science education tool. President Eisenhower's advisory council deemed the planetarium to be one of six outstanding innovative educational projects to emerge during his term. By 1970 there were over 700 planetariums in the U.S., fueled by federal NDEA matching funds and Title III grants.

CURRENT TRENDS SUGGEST THAT DIGITAL DOMES MAY EMERGE AS A KEY COMPONENT IN A FUTURE DIGITAL INFRASTRUCTURE DESIGNED TO AGGREGATE AND DISSEMINATE EXPERIENTIAL DATA, INFORMATION, KNOWLEDGE, SIMULATIONS, ART, AND PERFORMANCES ACROSS A RANGE OF DISCIPLINES IN SCIENCE, ART, AND THE HUMANITIES.

The development of the planetarium as an immersive storytelling medium continued with the advent of special effects projectors and edge-blended "all-sky" slide projectors. The complexity of these systems was successfully managed with theater automation systems, allowing layering of visual effects triggered by timecode streaming from a multichannel sound track. Eventually, automated programs displaced the traditional live presentations in many institutions and were more akin to a cinema with push-button operation and a pre-recorded soundtrack.

The digital age began in 1983 with the E&S Digistar, a vector-based (calligraphic) star projector using a single hyperbrilliant CRT and fisheye lens originally developed for military flight simulation. Sales of optomechanical planetariums steadily eroded after the introduction of Digistar. In 1981, after seeing an early Digistar demonstration, Claire and Everett Carr of the BOCES Planetarium in Herkimer, New York foresaw the next generation of full-dome systems, which would have ". . . four or more large screen projection TVs with wide angle lenses covering a planetarium dome," plus CRT projectors and HDTV players, and the "ultimate replacement of electromechanical planetarium projectors" with "digital projectors" (Carr and Carr 1981). Military simulators were the first to pioneer this technology (Fisher 1987). Next came Alternate Realities Corporation, which introduced single-projector fulldome projection in 1994 (A Larger Vision of Virtual Reality 1994). It was not until 1996, however, that multi-projector, raster-scan, electronically edge-blended systems were used in the planetarium dome. Early demonstrations were conducted by Goto, E&S, and Spitz, followed by systems from Sky-Skan, Zeiss, R.S.A. Cosmos, and others (Lantz 1997; Scott and McColman 1999).[1]

Fulldome equipment vendors needed programming to sell their wares. As standards were developed—primarily the dome master format, an equidistant polar or "fisheye" mapping—independent and institutional producers came to dominate the fulldome show market. Early programming was almost entirely rendered by 3D computer graphics or produced using spherical compositing techniques. The same holds true today, although live-action is slowly making its way into an increasing number of show productions. This is in sharp contrast to giant screen films, which are nearly all live-action based.

DIGITAL DOMES TODAY

There are currently 820 fulldome theaters listed on the Loch Ness Productions Fulldome

Theater Compendium.[2] They range from small portable domes and fixed educational domes to digital public domes. (For a typology, see Appendix A.)

Modern digital dome systems have resolutions ranging from 1-2 million pixels for smaller portable domes and digital classrooms, to over 30 million pixels in the world's largest, most advanced systems. Unlike giant screen cinemas, digital domes are scalable from small domes of 3-meter-diameter to the world's largest dome theaters with a diameter exceeding 35 meters. Approximately 33 percent of all digital domes have greater than 2000 × 2000 pixel resolution. Most high-end programs are produced at a 4000 × 4000 pixel dome master resolution to provide near-cinema quality resolution. (For a comparison of digital domes and giant screen theaters, see Appendix B.)

To serve this growing community, there are currently more than eight international fulldome film conferences, tradeshows, and festivals. (For a list, see Appendix C.) Numerous regional planetarium conferences also offer annual fulldome showcases and vendor tradeshows.[3] However, the vast majority of planetariums remain focused on astronomy-related science education; many still carry the moniker of "star theater" or "astronomy center." Regional planetarium societies must continue to serve this base, and in fact are largely comprised of and managed by members who are deeply passionate about astronomy and space science. Since 80 percent of all planetariums are still based on optomechanical projection of stars, digital technologies are but one area of emphasis at planetarium conferences. (Digital planetariums do receive a disproportionate focus at these meetings, since they are the locus

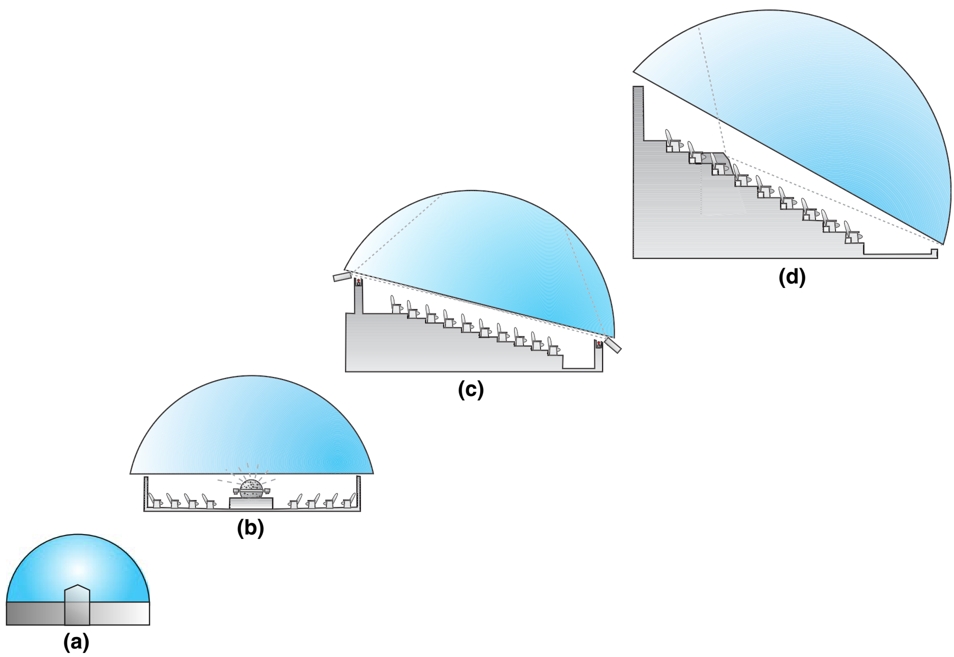

Figure 2. Digital dome spectrum: a) portable, b) classic planetarium, c) tilted dome, and d) giant screen dome.

of innovation in this profession). IMERSA (Immersive Media Entertainment, Research, Science and Arts) was founded in 2008 as a trade association dedicated entirely to the digital dome medium, not just in museums and science centers, but across other markets including themed entertainment, giant screen digital cinemas, and mobile events domes.

DIGITAL DOMES AND GIANT SCREEN FILM

The majority of programming for digital domes consists of linear, immersive science documentaries. Giant screen theaters within museums and science centers—some of these theaters are domes—also feature science documentaries and have been exploring the adoption of digital projection technologies. Some have questioned whether there might be a future convergence between large full-domes and giant screen cinemas (Lantz 2006; Rubin 2010).

There are about 125 giant screen domed cinemas in the world (Oran et al. 2009), primarily IMAX Dome and Omnimax branded theaters. With a 15-year head start in adapting digital playback, real-time image generation, and projection onto large immersive screens, fulldomes have much to teach their aspiring giant screen cousins. The largest, brightest, and highest resolution fulldome theaters—which are currently expensive to own and maintain—do indeed rival or even exceed giant-screen film theaters in image quality and appearance (Sky-Skan 2008). In a recent side-by-side comparison with 15 perf/70 mm film, the most recent generation of 4 K pixel Digital Light Projector video projectors[4] came amazingly close to giant screen film in image quality and brightness on Moody Garden's 80-foot-wide screen in Galveston, Texas.[5] Given the high cost of 70 mm prints compared to the much lower cost of digital distribution, combined with the lower purchase price and lower lamp cost of digital projectors, the adoption of digital projection in giant screen theaters is likely to accelerate.

There are fundamental operational and cultural differences between giant screen cinemas and digital planetariums. (For details, see Appendix D.) These differences in culture, operating models, and theater designs are arguments against a wholesale convergence of giant screen film and digital dome markets. However, the underlying similarities in immersive projection technologies, distribution format, and production tools creates a powerful synergy between digital domes of all types and emerging giant screen digital cinemas. Already the communication between these communities—fostered by vendors and the Giant Screen Cinema Association, IMERSA, the International Planetarium Society, the Association of Science and Technology Centers, and the Themed Entertainment Association—have yielded productive cross-pollination of research, science, education and art.

Below are highlights of selected emerging trends—both within and outside of the full-dome profession—that, taken as a whole, are suggestive of future directions for this medium.

EMERGING TRENDS

Greater Sensory Realism

Ideally, in the digital planetarium, when the lights go down, the theater disappears and the visitor's experience of reality is taken over by the presentation. Higher frame rates and advanced spatialized audio—along with increased brightness, contrast, and resolution offered by next-generation projection systems—promise to increase the visitor's sense of "presence"—the illusion that one is actually immersed in a virtual environment.

High Frame Rates

Fulldome programming is already largely produced with a 30 fps (frame-per-second) frame rate, which offers a perceptible improvement over the 24 fps standard used in cinemas and giant screen theaters. However, when camera motion pans, tilts, or navigates through a scene, two phenomena decrease apparent resolution and create powerful perceptual cues that conflict with the sensation of presence. The first is *judder* (caused by spatial separation of moving images between individual frames). The second is *motion blur* (image blurring caused by motion within the exposure time of a single frame). It has long been known that higher frame rates (typically, 48 fps for film or 60 fps for video) substantially reduce motion blur and judder, thereby increasing apparent realism of moving scenes. Higher frame rate programming is more costly to produce, even with the advantage of digital cinema. The results are stunning, however. Most fulldome servers and projectors are capable of playing 60 fps content. As the economics of fulldome production improve and competition increases, producers may finally start releasing premium shows at higher frame rates.

Spatialized Audio

The power of spatialized audio is often overlooked in surround-video system design. New systems are emerging that provide enhanced audio spatialization, including vector-based time and amplitude panning exploiting the "precedence effect" (Rodigast 2006), Ambisonic B-format spherical surround techniques (Gaston, et al. 2008), and 3D holographic wavefront synthesis—also known as wave field synthesis (Rodigast 2006; Schnelle and J. Bärwolf 2006). These systems are capable of placing virtual sounds, recorded as individual "stem" tracks, anywhere inside or outside of the theater space. Tight coupling of sound and image sources provides powerful cues for immersive storytellers. Standardized formats for distribution will need to be adopted for next-generation audio formats to achieve widespread use (Gaston, et al. 2008).

TRENDS IN CONTENT CREATION

The future utility of digital domes depends on the availability of quality source material. Future growth is likely in two areas in particular: 3D scientific datasets and live action image capture.

Live Action Immersive Cinema

Nearly all linear fulldome shows are produced using computer animation, with very limited use of live-action cinema. A few live-action video features have been produced in fulldome format (Yu, et al. 2007; Singer and Pfänder 2007). The medium currently suffers from the lack of an affordable digital camera capable of shooting a 1:1 aspect ratio fisheye image with 16 million pixels or more. High-end 4K pixel digital cinema cameras only provide just over half of the required vertical resolution with their 16:9 aspect ratio imagers. The introduction of an affordable 4K × 4K fulldome camera will likely result in more live action productions, bringing the medium closer to the realm of giant screen cinema. The technology currently exists to create such a camera. A single-lens, dual 4K chip design, and new higher resolution imagers are due on the market soon.

3D Scientific Datasets

Curatorial interest in 3D scientific datasets is fertile ground for collaborative projects between museums and universities, and can benefit not only digital planetariums, but the entire spectrum of science-based programming. Giant screens, television, museum exhibits, and the Web offer possibilities for artists, filmmakers, performers, publishers, and other content creators.

A VISION IS EMERGING OF A WORLDWIDE NETWORK OF IMMERSIVE DOMES ACCESSING CURATED SCIENTIFIC DATASETS, REMOTE CAMERAS FOR TELEPRESENCE, MULTICASTING OF CELESTIAL EVENTS, NETWORKED VIDEO GAME TOURNAMENTS, AND MORE.

Interestingly, preparing digital data for widespread dissemination through a storytelling medium can also require skills that may lie outside the capabilities of the scientists or artists who are generating the data. In some cases it is appropriate to simulate or extrapolate missing data. Photographic imagery must sometimes be retouched, or a time series smoothed to look pleasing to the eye. Data preparation must be performed with great care, often in cooperation with the scientists or artists who generated it, in order to accurately communicate the underlying scientific principles or artistic interpretation. Appropriate metadata must also accompany the visual and auditory datasets. These are already familiar tasks for the museum curator who prepares digital data for exhibits, Web, and other media (Müller 2002). The need to feed the dome has resulted in a unique curating and distribution model that informs new possibilities for museums.

Nearly all digital planetariums have the ability to navigate complex 3D datasets in real time. Planetariums have focused on astronomical and astrophysical datasets, and the work done in this area stands as a model for what is possible across all of the sciences. Perhaps the best model for successful curating and distribution of complex and extensive scientific datasets is the Digital Universe Atlas. Essentially a macroscopic model of the known universe, the Digital Universe was initially developed by the Hayden Planetarium of the American Museum of Natural History via a 1998 NASA grant (Abbott, Emmart, and Wyatt 2004). It includes numerous datasets: nearby stars, star clusters, nebulas, extrasolar planets, nearby galaxy clusters, the Sloan Digital Sky Survey, and multispectral sky maps such as the WMAP's cosmic microwave background radiation map of the most distant edge of the known universe (Digital Universe Atlas 2011).

The Digital Universe is distributed for a fee to three major vendors for packaging with their proprietary 3D navigation applications, which in turn are sold to hundreds of digital planetariums worldwide. In addition to distribution to digital planetariums for live planetarium programs, the Digital Universe is also available free via Web download for viewing using an application called Partiview. Derivative works of the Digital Universe are also used in numerous AMNH productions and products, including their space shows (which are widely available worldwide), high definition Science Bulletins, and in an interactive station in their Moveable Museum.

The Digital Universe Atlas stands as an example of how electronic datasets and simulations can be successfully curated, packaged, and redistributed for giant screen immersive viewing, and repurposed across multiple digital media distribution platforms. In addition, it has empowered a new generation of interactive storytellers who navigate audiences in real-time through complex scientific datasets (Emmart 2005).

Networked Domes

The Internet has forever changed the world, providing nearly instant access to an enormous and ever-expanding knowledge base. A vision is emerging of a worldwide network of immersive domes accessing curated scientific datasets, remote cameras for telepresence, multicasting of celestial events, networked video game tournaments, and more (Lantz 2005; Emmart 2005; Lantz 2009a; Lantz 2008). Already dome theaters are using "domecasting" to connect dome theaters using standard Internet connections. The core technologies for an ultra-wideband "dome grid" interconnecting universities and dome theaters have already been demonstrated by the OptIPuter project, which interconnects gigapixel displays worldwide in a collaborative scientific "cyber-infrastructure." At least one pioneering institution has joined CineGrid, a non-profit institution providing access to the core photonic networks employed by the OptIPuter project.

Domecasting

While the infrastructure does not yet exist to multicast ultra-high-resolution digital planetarium imagery to digital domes around the world, one vendor (SCISS AB) provides a 3D application capable of "domecasting" or remotely controlling dataset navigation in other dome theaters (Uniview 2011). Domecasting has primarily been used by curators to train presenters worldwide on how to navigate their complex datasets. For instance, at a recent opening of the Ghana Planetarium in West Africa (made possible by generous donations from fulldome planetarium vendors) a domecast included participants in Minnesota, Wisconsin, North Carolina, New York City, Colombia, and Accra in Ghana. Carter Emmart, director of astrovisualization at the Rose Center for Earth and Space at the American Museum of Natural History, took participating domes on a tour to the edge of the universe. (Emmart originally introduced the concept of domecasting [Emmart 2005]).

OptIPuter Project

Led by the California Institute for Telecommunications and Information Technology (Calit2), the OptIPuter project is a "a powerful distributed cyber-infrastructure to support data-intensive scientific research and collaboration" (Jeong, et al. 2010). There are now 59 OptIPuter sites featuring ultra-high resolution displays called OptiPortals with tens or hundreds of megapixels that allow collaborative viewing of multi-gigapixel images, 3D datasets, and 4K video from local or remote computers through wideband optical fibers.

These systems are based on an architecture called SAGE—a Scalable Adaptive Graphics Environment. This network-centered architecture allows collaborators to simultaneously run multiple applications on local or remote clusters, and share them by streaming pixels from each application over ultra-high-speed networks to large OptiPortal displays.[6] Using SAGE it is possible to interactively navigate multi-gigapixel images served by a computer in the

Netherlands using an OptiPortal at Calit2 in San Diego, for instance. Research applications for the OptIPuter network have been demonstrated in biomedicine, geosciences and geoinformatics, marine microbial analysis, real-time environmental observatories, space visualization, and technology training (Pieper, et al. 2009).

This project, although designed for collaboration between researchers using high-performance computing centers, gives us powerful insight into what is possible in a future network of digital domes (Lantz 2005), and provides a possible avenue of collaboration between academic researchers and digital domes-museums. Key to the OptIPuter project is access to GLIF, the Global Lambda Integrated Facility, a global consortium of users employing shared "dark" (dedicated wavelength) fiber optic channels creating a very high bandwidth—in many cases over 10 Gbits/second—Lambda Grid network (Brown 2004). GLIF is easily accessed through CineGrid, a non-profit organization with a mission to "build an interdisciplinary community that is focused on the research, development, and demonstration of networked collaborative tools to enable the production, use and exchange of very-high-quality digital media over photonic networks."[7] At least one digital dome—the Morrison Planetarium at California Academy of Sciences—has joined CineGrid in an effort to pioneer dome grid applications in their fulldome theater.

DELIVERING MEANINGFUL EXPERIENCES

The reason for all this technology, of course, is to deliver meaningful experiences to visitors by giving them lasting value, whether cognitive (increased understanding) or affective (increased motivation or inspiration). It is important to understand the unique advantages of sensory immersion, and to explore various genres of immersive media and how they can best utilize these strengths. The medium is well suited for productions that combine art and science, for instance, leading to the development of a wide range of SciArt programming. While the specific missions of museums vary, it has been argued that imparting a sense of social responsibility is a universal imperative. The capability to deliver powerful media experiences ought to translate into the capability to more deeply influence the visitor's core beliefs and worldviews. The focus on transformation is an emerging trend in fulldome programming.

Immersive Education Research

Research has suggested that immersive media—including giant screen films—can improve learning. A recent study suggests that fulldome programming communicates concepts better, creates a greater interest in learning, and is a more effective medium at conveying scientific concepts than a movie-theater-style screen or television (Heimlich, Sickler, Yocco, and Storksdieck 2010). Various studies in virtual environments show that greater immersion and "sense-of-presence" (as compared to non-immersive environments) is associated with better task performance, higher satisfaction levels, increased learning effectiveness, and increased student engagement (Yu 2005).

In general, visualizations have been found to increase understanding by representing data in visual form, allowing efficient human visual capabilities to perceive and process abstract data (Ware 2000; Card, MacKinley, and Shneiderman 1999). Planetarians maintain that greater spatial understanding is possible with immersive visualization, an important factor in astronomy education, which requires visualization of spatial relationships to explain, for instance, seasons or eclipses (Yu 2005). In addition, live interpretation and navigation of visuals allows flexibility in meeting the needs of diverse audiences who are often free to interact with the presenter.

Arts education has been correlated with increased learning in science, technology, engineering, and math fundamentals (Gazzaniga 2009). Similarly, it is possible that immersive experiences can stimulate unique brain states that are useful in achieving important affective and cognitive educational goals. Digital domes are an experiential medium: instead of talking about places or things, they take people there. The contemplative nature of many fulldome programs provides room for the mind to wander—a possible stimulant for creative thinking (Fries 2010) and the delivery of restorative experiences (Packer and Bond 2010).

Few would argue that the immersive media experience is not psychologically more intense than other media. But the exact nature and value of this impact on visitors requires closer examination. Researchers admit that more studies are required to understand the efficacy of immersive media over other forms of media (Fraser, Yocco, and Sickler 2010; Shanks 2010).

SciArt Programming

The rich content of scientific information, visualizations, and simulations in 3D formats will inevitably be used by artists and storytellers to create unique artistic works. So-called SciArt (also referred to as ArtScience) has been pioneered by planetariums over the years with “music under the stars” and other fusions of scientific visualizations and live or pre-programmed music (Lantz 2009c). It has been argued that the combination of music, art, and science-based visuals could actually be instrumental in the dissemination and assimilation of new scientific understandings into personal and cultural cosmologies (Lantz 2009b). Digital planetariums combine these modalities in a powerful group immersive setting. The innovative use of live performance is a particularly successful trend in SciArt (Lantz 2009b; Rubin 2010; Neafus and Yu 2007). Several SciArt university programs have launched recently. Donna Cox’s eDream (Emerging Digital Research and Education in Arts Media Institute) at the University of Illinois at Urbana-Champaign, for instance, is designed to “explore and express human creativity through emerging digital technologies.”

Focus on Transformation

What many museums seem to share, in one way or another, is a desire to influence how we see our world in ways that will make a better world for all. Robert Janes’s vision of a Mindful Museum would seek to impart a sense of social responsibility in visitors regardless of the museum genre (Janes 2010). The digital dome is a powerful medium for influencing core beliefs and worldviews (Lantz 2009b; McConville 2007; Worldviews Network 2011). (For one possible model of worldview transformation, see Appendix E.)

The hope is that affective and cognitive educational programming and cultural arts and entertainment programming can be designed to have a positive, lasting effect on visitors and as a result, foster a better world.

STANDARDS, GUIDELINES, AND SPECIFICATIONS

It is generally recognized that—if the fulldome medium is to thrive—it will be necessary for theaters to adopt industry standards or guidelines for content creation, distribution, and exhibition (Howe 2004; Lantz 2004a; Lantz 2004b). To the credit of fulldome producers and vendors, the dome master format has served well as a format for show exchange (Wyatt and Lantz 2005). Most fulldome theaters are capable of accepting dome masters and formatting them for exhibition, albeit sometimes with vendor assistance. This has allowed the rapid growth of fulldome titles and has even resulted in digitization and formatting of a handful of giant screen films for domes.

Theater design and presentation systems need standardization to assure consistency in the quality of fulldome productions from screen to screen. Extreme differences in brightness, resolution, contrast, gamma, and color gamut confound fulldome producers and distributors. And there is virtually no standard format yet for the cross-distribution of real-time 3D programs between theater systems from different vendors. IMERSA is in the planning stages of developing industry specifications and guidelines intended to steer future projection system designs and installations into more uniform image quality. In addition, IMERSA is a participant in the NSF funded Digital Immersive Screen Colloquium for Unified Standards and Specifications (DISCUSS) which has developed an initial draft for Digital Immersive Giant Screen Specifications (DISCUSS 2011). It is hoped that unifying fulldome theater standards with giant screen digital theater standards will facilitate cross-purposing of content and open giant screens to alternative real-time programming developed initially for fulldome theaters.

THE FUTURE

The current trends in digital domes suggest far-reaching possibilities for this emerging medium. Essentially, the digital dome is a group immersive portal into the world of electronic information. Many recent advances in science rely upon or culminate in scientific visualizations of experimental information or simulations to provide rapid understanding of complex phenomena. Scientific visualization—of the structure of the universe, galaxy collisions, fluid flow, atomic models, and quantum effects—provides scientists with windows into phenomena that are either too large, too small, too fast, or too slow to directly observe (Lantz 2009b). Digital domes allow group exploration and interpretation of these phenomena either in real-time by navigation of 3D datasets or through carefully rendered visualizations in an immersive, high resolution, highly compelling format.

The vision emerges of a future global "DomeGrid" that would curate and disseminate a publicly accessible navigable model of the known physical universe based on the latest scientific theories and research (Lantz 2008). The data and programs would be curated by experts in a global network of universities, museums, and science centers; assembled into a coherent, visually searchable collection; and distributed through a global fiber-optic network. The DomeGrid would reach hundreds of digital domes worldwide, which in turn serve hundreds of smaller regional and portable domes. The resulting datasets comprise a model of the known universe over time, space, and scale—ranging from the macroscopic universe to the microscopic world of quantum physics, biology, history, art, philosophy, engineering, architecture, math, and all of the sciences. In addition, the DomeGrid would have real-time immersive camera feeds. Visitors could be transported to an animal watering hole in Sub-Saharan Africa; the Grand Canyon in the Southwest United States; or even to an immersive camera mounted on the International Space Station.

Such an endeavor is best accomplished through a global effort, managed by a consortium of universities, museums, and science centers, and funded by multiple agencies.[8]

The amount of digital content that can be formatted and presented in digital domes is already vast, and will likely increase by orders of magnitude in the coming decades. Data must represent the best available information, and metadata must sufficiently and accurately describe the associated data. Experts could organize this information using a software interface that is essentially a high-performance, expert-driven version of MediaWiki. The DomeGrid would be hosted by high-performance computing centers at select universities, science centers, and museums, or perhaps sponsored by commercial "cloud" providers such as Google or Amazon.com.

In the digital dome these assets are woven into a story arc or logical progression that is emotionally as well as intellectually engaging. Content creation for exhibition in digital domes—and group navigation of content—demands superb storytelling skills. The tools of storytellers include authenticity, grand scale, dramatic visuals and sound, and a compelling plot—what Counts calls Spectacular Design (2009).

Because of their real-time capabilities, new storytelling and performance modalities are possible. Students will bring assets created at home or classroom into the dome for competitions or show-and-tell. Virtual subject matter experts will reach out to larger audiences, controlling their visual and aural experience. Virtual presenters or performers can also teleport into digital domes via a 3D avatar controlled by gestures (a technology now available in at least one commercial video game). Telepresence will allow presenters to virtually teleport entire audiences to remote locations in real-time.

The other interesting effect of digital domes on museums is to re-assert the need for a brick-and-mortar facility: a place where people go to learn as a group. The concept of a virtual "museum-as-information" that is available anytime, anywhere (Miller 2010) is supplemented by the idea of a museum as a place to actually experience information in compelling formats that are not available elsewhere else. **END**

NOTES

1. A current list of digital planetarium vendors can be found at http://www.lochnessproductions.com/fulldome/fulldome_resources.html.
2. See http://www.lochnessproductions.com/lfco/lfco.html.
3. For more information on regional planetarium conferences worldwide see http://www.ips-planetarium.org/or/affiliates.html.
4. The 4K pixel DLP is manufactured by Texas Instruments. Accessed Jan. 31, 2011 at http://www.dlp.com/cinema/dlp-enhanced-4k/.
5. The author witnessed this recent demonstration at the Digital Cinema Symposium held at Moody Gardens in Galveston, Texas on Jan. 26, 2011. The Barco DP4K-32B projector produced a bright (reportedly 17 foot-Lambert) image on the 80-foot-wide screen that, in some scenes, actually looked better than the 70 mm/15-perf film reference material provided by FotoKem in split-screen tests.
6. See SAGE project website at http://www.sagecommons.org/.
7. For more information on CineGrid see http://www.cinegrid.org.
8. Standard licensing agreements would allow distribution of the full-resolution datasets and derivative works, requiring in some cases the payment of licensing fees. These valuable datasets would be made available to content creators and vendor partners across all media: film, television, mobile, Web, and videogames. Because the original assets are in 3D immersive format, they can be repurposed to nearly any media format, a practice known as cross-platforming or transmedia (Jenkins 2003).

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APPENDIX A

The range of fulldome venues within museums and science centers

Categories include approximate percentages worldwide (Petersen 2010):

1) Small portable domes (21 percent). Primarily used for community outreach, portable fulldomes almost exclusively use single-lens fisheye projectors that are easy to set up. They deliver an effective immersive experience and sufficient resolution for educational presentations.

2) Fixed educational domes (38 percent). These are typically smaller domed classrooms that may not offer public programming. Because they are fixed in nature they can provide an enhanced experience over portables.

3) Public domes (41 percent). These are digital domes that are open to the

> public at least part-time and must attract voluntary audiences by virtue of the quality of the presentation. Type C domes typically have higher resolution video, surround-sound and other enhancements that provide greater entertainment value in addition to meeting base curriculum needs.

APPENDIX B

Digital dome projection and production technologies

Most digital dome venues provide a full 180 x 360-degree hemispheric field-of-view as defined by the "dome master" digital mapping format shown in figure 3. By comparison, the giant screen IMAX dome format is an offset (truncated) 180-degree fisheye format that covers about 130 degrees of verticality on the dome screen, as shown in figure 4 (Max 1983). In addition, few IMAX films are shot specifically for the dome, while most digital dome programming fully utilizes the hemisphere with geometrically correct spherical rendering. The resulting content closely simulates actually being there, with trees, buildings, and other scenery towering above visitors. It is well known that wide field-of-view imagery stimulates the "opto-vestibular" response in the brain, activating powerful motion cues (Lappe, Bremmer, and van den Berg 1999). A camera pan in an immersive theater can provide the illusion that the entire theater is rotating, allowing producers to easily deliver "thrill ride" type experiences. Many have argued for a new cinematic language for immersive cinema storytelling (Shedd 1989; Yu 2008). Producers in this medium often take care to slow down camera motion to reduce the unpleasant sensation of vertigo, sometimes referred to as "simulator sickness" (Johnson 2005).

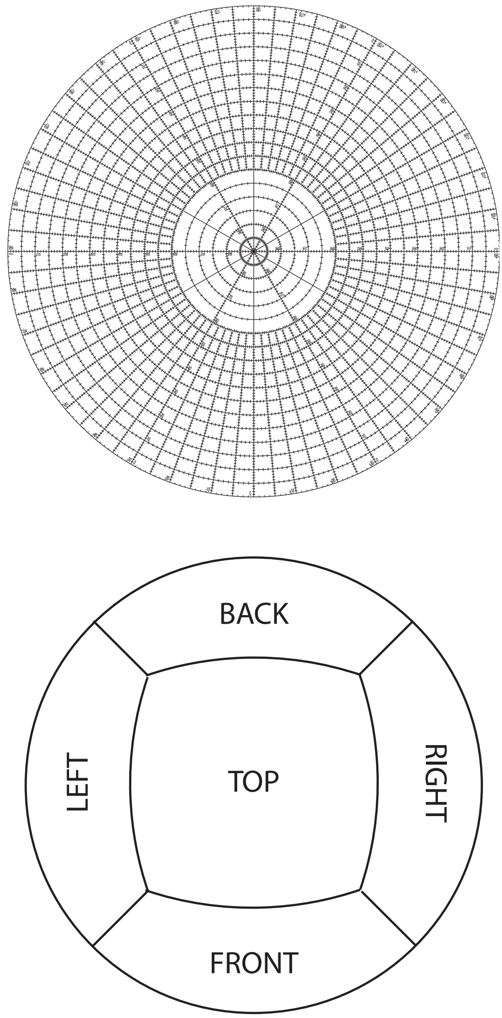

Figure 3. Dome master mapping (Wyatt and Lantz 2005).

Frequent cuts between scenes are also thought to be distracting, since the mind takes time to build cognitive maps when presented with a new immersive environment (Wyatt 2005).

Most public theaters also utilize 5.1 surround sound (Gaston, Dougall, Connelly, Merkle, and Thompson 2008). A small number of theaters have specialized sound systems, such as the 15.1 surround system at the Denver Museum of Nature and Science and the 23.2 speaker

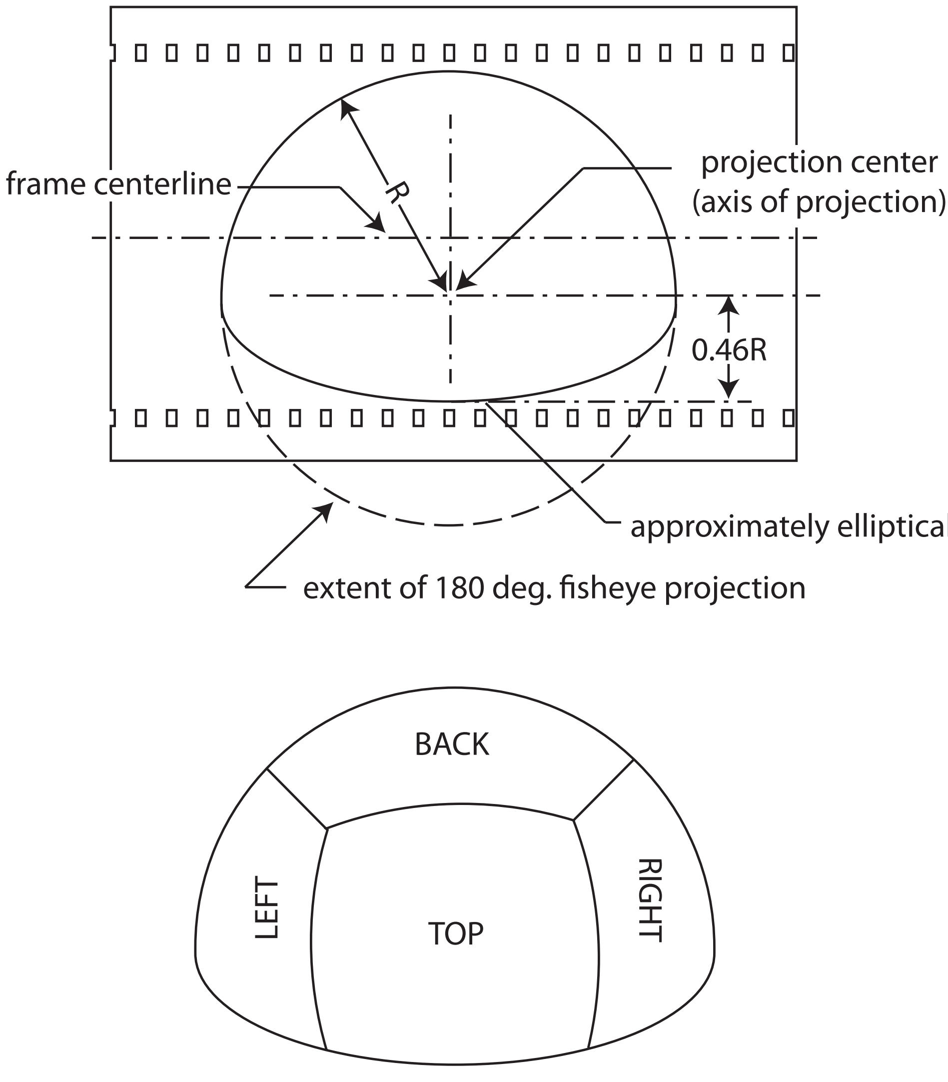

Figure 4. IMAX Dome Mapping (Max 1983).

surround at the American Museum of Natural History. Many giant screen cinema professionals believe that audio is around 60 percent of the giant screen experience. Spatialized audio is also a powerful tool for directing visitors' attention around the dome toward the action.

Like giant screen cinema, digital domes are able to deliver the full range of visual image capture and display (in both 2D and stereo 3D modes), including source imagery in hemispheric format produced through live-action cinematography (such as conventional cinematography that has been digitally re-mapped for the dome); 3D computer graphics modeling, rendering, and animation; 3D object or scene capture, rendering, and animation, including scenes captured using LIDAR or photogrammetric techniques; 2D, 3D, or spherical illustrations including compositing; scientific simulations of phenomena from mathematical models or experimental data; informational display including photos, text, video clips and other material that is composited onto immersive backgrounds.

In addition there are several modes of content sourcing, including linear playback of pre-rendered content; random access of pre-rendered clips allowing branching or manual on-demand triggering of content; and real-time 3D, allowing navigation and exploration of objects, scenes, datasets, and so on.

Today there are over 200 linear fulldome titles produced specifically for digital domes by over 50 producers (Petersen 2010). Programs include educational-documentary and fact-based narrative programs for science and humanities education (primarily astronomy-related but now expanding into the natural sciences, biology, archeology, heritage sites, and cultural mythology); fictional storytelling; Sci-Art (also called ArtScience) using scientific visualizations, data, or imaging in visual/musical productions; and other cultural and fine arts entertainment, including live performances and audience interactive experiences (Lantz 2009c). Several digital domes worldwide have also embraced stereoscopic 3D (S3D) projection and a small number of fulldome programs are now available in S3D (Laatsch 2008).

APPENDIX C

International fulldome film conferences, tradeshows, and festivals

- IPS (founded 1970), the biennial conference of the International Planetarium Society, a tradeshow with heavy focus on fulldome technologies.
- Fulldome Video Showcase, ASTC (founded 2003), produced by Spitz and now co-located with the Association of Science and Technology Centers annual conference.
- DomeFest, Albuquerque, NM (founded 2004), a fulldome art film festival and symposium produced by ArtsLAB at the University of New Mexico and hosted by UNM and the New Mexico Museum of Natural History and Science.
- IMERSA Fulldome Summit (founded 2004), a technical and creative symposium now hosted by the Immersive Media Entertainment, Research, Science and Arts trade association, which offers a symposium and curated film showcase.
- FullDome Festival, Jena, Germany (founded 2007), a fulldome film festival hosted by the Jena Planetarium.
- Immersive Film Festival, Espinho, Portugal (founded 2009), a fulldome film festival held at Centro Multimeios de Espinho and produced by Navegar Foundation.
- ʻImiloa Fulldome Film Festival, Hilo, Hawaiʻi (founded 2010), a fulldome film festival hosted by the ʻImiloa Astronomy Center, part of the University of Hawaiʻi at Hilo.
- Fulldome U.K. in Birmingham, U.K. (founded 2010), a two-day fulldome conference and festival with screenings, presentations and discussions hosted at the Thinktank Science Museum.

APPENDIX D

A comparison of giant screen cinemas and digital planetariums

Unlike giant screen dome theaters, which are relatively standardized—most are designed by Imax Corporation (Shaw and Creighton 1983)—digital dome theaters compete with each other in design configurations and projected image and sound quality. This is partly due to the variety of vendors delivering these systems, the large choice of audio and video delivery technologies, and legacy theaters that upgrade to digital but cannot upgrade their theater design. One could enter a fulldome theater and find concentric seating (12 percent), a non-tilted dome and seating deck (85 percent) or dome tilts up to 30 degrees. Furthermore, some projection systems are still actually analog CRT-based with very low brightness (0.1–0.5 foot-Lamberts, as opposed to giant screen domes which often exceed 2 foot-Lamberts). Nevertheless, fulldome programming is being successfully formatted and distributed to this wide spectrum of theaters, and efforts are underway to develop recommended specifications for all theater types.

Theater design: Fewer than 11 percent of all digital domes would meet the 60-foot-or-greater diameter required by the Giant Screen Cinema Association in order to be considered a “Giant Screen” cinema (Oran et al. 2009). Fewer still have tilted domes and stadium seating, which are standard in giant screen domes.

Technological complexity: High resolution digital domes can be technologically complex and often require a full-time technician for show encoding and system maintenance in addition to a projectionist. Giant-screen film-based dome theaters are accustomed to a single, powerful projector, and have a bias against of multi-projector configurations.

Program duration: Giant screen films are typically a 40–45 minute in duration, while fulldome programs are largely 20–23 minutes long allowing the option of a 30-minute theater cycle time or the addition of a live “sky tonight” tour.

Regional programming: Many digital planetariums prefer to maintain a regional flavor to their programming, either with in-house productions or customized content. Giant screen programming is widely syndicated with minimal regional customization.

Astronomy bias: Many digital planetariums are mandated to operate as astronomy centers or star theaters and will not stray into the larger range of science and humanities topics featured in giant screen films.

CGI versus live-action programming: Giant-screen theaters primarily show live action films, while fulldome theaters show mainly CGI content.

Interactive programming: While “alternative programming” is given lip service in giant screen digital cinema discussions, extensive real-time 3D capabilities have been featured in digital domes since Digistar debuted in 1982, and audience interaction with live presenters has been a staple of planetariums since their inception.

Immediate access to scientific data: Increasingly, science is best communicated via scientific visualizations and simulations. Digital domes have immediate access to 3D datasets when released and can roll this into live interactive presentations. Giant screen films can take years to fund and produce, missing out on the latest discoveries.

Financial model: Digital planetariums employ a buyout or flat-fee annual licensing model and most are not set up to do auditable attendance accounting. Giant screen film theaters employ a gate-share model that benefits producers of high-grossing films.

Quality standards: Giant screen film theaters generally adhere to (or aspire to) quality standards set down (or mandated) by Imax Corporation. Image and acoustic qualities of digital dome exhibition varies over a wide range without firm standards or specifications. (IMERSA is now working on standards and guidelines for future theaters.)

Scalability: Digital domes come in all sizes and flavors, from small 15-foot-diameter portable domes to large 200-foot-diameter inflatables. This creates unique challenges (and opportunities) not experienced by giant screen producers and distributors.

Range of uses: The large range in exhibition quality and dome size is partially due to the large range of uses for these spaces. Some digital planetariums operate as classrooms only, others as public theaters, making for huge differences in culture and operating models. Giant screen cinemas are now seeing a similar dichotomy since the introduction of giant screen digital film theaters optimized for Hollywood films.

Anti-piracy/content protection: Giant-screen digital theaters employ DCI-compliant systems and distributors are now accustomed to delivering encrypted DCP's. Lack of a similar standard is an inhibitor to fulldome producers seeking to enter the giant screen market.

Formatting content for the dome: Fulldome uses the entire hemisphere. Giant-screen film domes use only the partial hemisphere. As such, films created for giant-screen domes (nearly all of which were produced for flat screen, without much/any accommodation for a partial dome screen presentation) do not easily make the transition to fulldome.

APPENDIX E

Five levels of social consciousness

Derived from a model of worldview transformation (Schlitz, Cassandra and Miller 2010):

1) Embedded. Consciousness is shaped without conscious awareness by social, cultural and biological factors.

2) Self-reflexive. People gain awareness of how their experiences are conditioned by the social world through reflection and contemplative practices.

3) Engaged. People are not only aware of the social environment, but begin to mobilize an intention to contribute to the greater good in some outwardly directed way.

4) Collaborative. People see themselves as a part of the collective and begin to work with others to co-create or shape the social environment by collaborative actions.

5) Resonant. People report a sense of essential interrelatedness with others—a field of shared experience and emergence that is felt and expressed in social groups, and that stimulates social transformation.

It could be that the most transformational use of fulldome theaters is the delivery of programming designed to foster Schlitz's resonant sense of interrelatedness. Indeed, a new breed of producers is seeking to use the affective power of immersive media—emotionally evocative music, stunning visuals and clever storytelling—to invoke a deeper shift in worldview than is achieved by cognitive means alone (Williams 2008).