The Digital Planetarium

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Abstract. Planetarium technology is steadily shifting from opto-mechanical based projection to digital projection. This technology shift allows the consolidation of many individual projection sources into a single full-dome video-based display and image generation system. This shift is having a profound effect on planetarium show production, educational tools, theater automation, system maintenance, equipment life cycle, required staff and overall theater economics. The history of digital planetarium systems is reviewed, digital planetarium options are discussed, and the advantages of digital planetaria are weighed against opto-mechanical planetaria for both large public theaters and smaller teaching facilities.

In The Beginning…

In April 1983, Evans & Sutherland installed the first Digistar in the UNIVERSE Planetarium/Space Theater in Richmond, Virginia. Digistar was the world’s first computer graphics based planetarium projector, providing a calligraphic starfield using 4k x 4k addressable points on a single hyperbrilliant CRT tube, projected full-dome using a fisheye lens.

Detractors complained that the image was dim, the stars fuzzy and the colors a monotonic greenish-white. Others hailed the Digistar for its ability to project a true 3D database with high astronomical accuracy. One could actually leave the solar system and see constellations deform with proper star motion. In addition, the Digistar provided spherically mapped special effects that provided strong motion cues by stimulating the opto-vestibular response through wide-field imagery. Many of us have seen a “dim, fuzzy, greenish wireframe” asteroid image cause a theater full of children to duck down in their seats and scream as it “collides” with them. E&S has sold nearly 100 Digistar systems since 1983, an impressive feat for this small market.

Back in 1981, after seeing an early Digistar demonstration, Claire and Everett Carr foresaw the next generation full-dome systems that would utilize “…four or more large screen projection TV’s with wide angle lenses covering a planetarium dome,” utilizing CRT projectors and HDTV players [2]. Their dream has been realized, with nearly 30 raster-video based “digital dome” theaters open worldwide.

While edge-blending of video projectors on spherical screens has long been employed for expensive military flight simulators, it took a while for this technology to be simplified and adapted to planetarium applications. A 1995 course at ACM’s SIGGRAPH conference introduced the concept of military simulator technology for planetaria [3], with actual edge-blended systems installed by Spitz and Goto in 1997, followed by systems by SkySkan, E&S and Trimension in subsequent years.

With the exception of Digistar, however, digital dome theaters have not relied on video for primary starfield projection. With the emergence of higher resolution dome video systems and user-friendly night-sky generating software, this is now about to change. Planetarians will soon be declaring “look, Ma, no starball!” IPS 2002 promises to be remembered as the year of the digital planetarium.

Digital Dome Configurations

The last 5 years have been formative for new digital planetarium technologies. Hardware and software have matured, illusions have been dispelled, and many lessons have been learned. Manufacturers naturally choose to specialize in different technologies, resulting in numerous choices. Following is a brief overview of the many choices now available to planetarians, and their relative importance to the digital planetarium.
**Image Coverage.** Planetariums have had to choose what portion of their dome shall be covered with video imagery. Multiprojector solutions allow scaling from a single video channel (not really an immersive projection) to panoramic video (3 edge-blended projectors with 200° horizontal by 60° degree vertical coverage) to half-dome video (using 4 projectors – the video pan plus a zenith projector) to full dome coverage (six or seven projectors or single projector fisheye). Alternate schemes have been implemented as well including a 4-projector full-dome scheme.

The panoramic video format - initially promoted by Spitz - was offered as a cost-effective, entry-level medium for unidirectional theaters that places the image where it is needed the most – in front of the audience. Supplemented by all-sky slides, it remains an effective medium for traditional planetarium show presentation with reduced equipment, maintenance, and show production costs. However, panoramic video, while cost effective, is clearly unsuitable for primary starfield projection. The digital planetarium makes a full-dome video system more economical since an expensive optomechanical star projector is no longer required.

**Edge-Blends.** Multiprojector systems require individual “sub-frames” to accurately overlap on the dome screen – requiring precise spherical mapping – and they must be carefully masked to provide seamless edge-blending. A basic choice must be made between pre-rendered mapping/edge-blending and real-time mapping/edge-blending.

Pre-rendered blending is analogous to all-sky slides where a single fisheye image is split into separate geometrically correct images with applied soft-edge masks. When separately projected onto the dome, the sub-frames stitch back together to recreate the original spherical image.

Real-time blending accepts a source image in one of several multi-frame formats and applies real-time spherical warping and edge blends just prior to video projection. Formats may include multiple view planes (frustums) from a common viewpoint (common with real-time, multi-pipe image generators such as SGI Onyx and E&S ESIG), overlapped flat-plane views (such as a real-time computer desktop), multiple camera views from a live or pre-recorded camera cluster, or generic plane views split from a fisheye “dome master” frame. Real-time blends allow the display of real-time images. Pre-rendered blends do not.

Another approach to real-time edge-blending is the use of optical blend masks placed in the projector light path. Optical blends are inflexible. For instance, an optically blended projector cannot be used in widescreen mode since the blends cannot be removed. However, optical blending is useful with light-valve type projectors where the residual black level cannot be electronically blended.

Real-time image warping may be accomplished either digitally or by using the CRT projector geometry correction circuitry. Digital correction solutions, such as Trimension’s Mercator and Barco’s Warp-6, are more flexible but add to the system cost. They are the only means of real-time image mapping for light-valve type projectors which have a fixed pixel structure.

Recently introduced “fisheye” video projection systems circumvent edge-blending altogether. Single-lens solutions have numerous advantages over edge-blended systems, including lower maintenance, true “plug-and-play” operation, and easy interfacing to real-time computers. While black level remains an issue with fisheye video projectors, these systems are expected to find favor with planetaria due to their simplicity and ease of use.

**Projector Choices.** Nearly all digital dome theaters to date have utilized CRT projectors to attain the ultra-low black levels demanded when overlaying video onto an optomechanical starfield. The Zeiss ADLIP (all-dome laser image projector) laser-based video display can now approach the extreme black levels that were previously the exclusive domain of CRT projectors.

While CRT projectors are ideal for low black levels, they are also notoriously dim. A 9” CRT provides around 270 lumens, while a 12” CRT (only available from Barco) provides 500 lumens. Display brightness can be computed by

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\text{Display Luminance (foot-Lamberts) = } n \cdot \text{ORB} / A
\]
Where $n =$ number of projectors, $O =$ loss factor due to projector overlap, $R =$ dome reflectivity, $B =$ projector brightness and $A =$ dome surface area. CRT systems operate at around 0.1-0.2 fL. Contrast this with IMAX Dome theaters that have around 3.5 fL, or a 35mm film theater with 12 fL. The low brightness results in a serious loss of color saturation. Furthermore, dome reflectivity cannot be lowered to the ideal 0.3-0.4 level typical of film theaters, resulting in loss of contrast from cross-dome scatter. Settling on the CRT solution brings with it many compromises. Higher brightness can be achieved by “double-stacking” projectors, resulting in a 12-projector full-dome configuration.

In the digital planetarium, however, the black level is less of an issue – provided that it is a uniform black. Even a 600:1 contrast ratio projector can create an adequate night sky, as the brightest magnitude stars are 600 times brighter than the surrounding background. The resulting appearance is that of a night sky with a little light pollution – not an unusual sight. Since the stars are digital, a simple gamma adjustment can pull dimmer stars up over the residual light level for viewing. Dynamic range compression of star magnitude is essential in video-based starfields. Excessive compression, however, can make the recognition of constellations difficult, as the brightest naked-eye stars will no longer stand out against the background of dimmer magnitude stars.

Creating a uniform black level does present a challenge for edge-blended light-valve type projectors (LCD, DLP, D-ILA, etc.) unless they employ optical edge-blend masks in the projector light path. Single-lens fisheye projectors naturally produce a uniform black field.

**Image Generation.** The majority of existing digital dome theaters utilize pre-rendered shows streaming from hard-drive based video or graphics players as their primary image source. Graphics players from Spitz now offer 1600x1200 pixel resolution at 60 frames/second. A six-projector full-dome system with this resolution requires a 4k x 4k fisheye frame size – nearly the same as large-format film. Production at these resolutions is costly, however, even by Hollywood standards.

The pre-rendered production model is very similar to standard video or film production: write a script, develop the characters, storyboard the scenes, develop shot lists, execute the production of scenes then assemble them in post-production editing. Automated planetarium shows have long used a similar model, except that final editing utilized the dome as a compositing medium rather than a nonlinear video editing suite.

Many have objected to digital dome theaters as just another movie theater. Most optomechanical planetaria allow live interactive shows where the presenter manually dims the lights, starts and stops the star motion and fades up grids, constellation overlays and other effects at will. It is possible to pre-render a large selection of star motions and celestial effects to be randomly accessed upon demand. But a real planetarium needs the ability to create their own night sky for any desired time or place, whether it is pre-rendered or real-time.

Pre-rendered starfield generation utilizes special software that allows rapid (i.e. overnight) rendering of virtually all celestial phenomena and planetarium effects. Applications are now being introduced that simulate traditional planetarium effects: starfield rotations, planetary motions, constellation overlays, clouds, etc. Since the celestial objects are digital, they can be animated, zoomed, rotated and arbitrarily moved about the dome. Custom images can be accurately positioned in the night sky, or the entire starfield itself can be changed as needed. Standard slide projector banks can be simulated, as well as moving projectors. In the virtual planetarium, however, all projectors can be placed at dome center!

Spitz’s digital sky generating software is essentially a spherical compositing tool with timeline-based animation control, so it can be used to edit digital dome movies and clips, map videos onto the dome to create a virtual flat-screen theater, and more. Show editing is identical to planetarium show scripting, except that shows can be created and previewed in real-time on the desktop without the need for a dome. After the preview animations are completed, the final rendered frames are created for the specific theater configuration and loaded onto the graphics playback system. Alternate theater configurations can be rendered at any time using the edit file.

For those that demand the utmost in random access, real-time starfield generation provides the closest approximation to the operation of an optomechanical planetarium. However, star databases are far more extensive and are three-dimensional. Popular catalogs include the Hipparcos database with about 100,000 stars, and the Tycho star catalog with about a million, and are available online from the
European Space Agency [5]. Deep sky objects can be properly oriented in the night sky. A real-time 3D database allows the audience to leave the solar system and cruise through the galaxy and beyond. These systems turn the planetarium console into a spaceship cockpit. Operators can command real-time annotation of constellations, celestial objects, star data and more. Audience interactivity is possible as well.

While real-time systems have been very expensive in the past, the latest generation of graphics accelerator cards, such as those based on the NVIDIA GeForce4, have revolutionized real-time graphics. It is now possible to achieve realistic starfield simulation at a fraction of the cost. New software for digital planetaria will be more powerful and extensive than ever before, while running on a single high-speed PC or PC cluster for multiprojector systems.

Many have complained that real-time systems cannot match the image quality of pre-rendered images that include particle effects, ray tracing, rich compositing and other techniques that can increase render time to minutes or even hours per rendered frame. Real-time systems must always render in 1/30th of a second or more per frame. With the price drops in both graphics playback and real-time planetarium systems, most planetaria will soon be able to afford both as a seamlessly integrated planetarium system.

**Optomechanical vs. Digital**

Ultimately, the optomechanical planetarium cannot compete with the digital planetarium as a teaching tool. While accurate planetary motions can be displayed, the planets cannot be zoomed up to reveal surface detail and orbiting moons, and other celestial objects such as comets and asteroids cannot be accurately simulated. Likewise, Messier and other deep-sky objects cannot be zoomed up for closer inspection. While time can be speeded up to display annual motion of the planets, sun and moon, with the digital planetarium one can watch two galaxies collide over a billion year duration, or simulate the formation of the universe using the latest supercomputer models.

The digital planetarium is empowering to educators. Hubble images can be downloaded daily and dropped onto the celestial sphere. Students can draw their own planet images and the planetarium operator can move them accurately in the night sky. Planets, moons and deep-sky images produced by the local observatory or astronomy club can be proudly displayed in the sky as well. The sky tonight will include a faithful rendition of the latest comet or a breathtaking simulation of a coming eclipse. Hometown skylines will be added with ease. And the entire known universe will be available at the click of a mouse.

Regarding visual accuracy, video cannot yet compete with optomechanical star projectors. But this issue is most often one of aesthetics more than educational value. Digital planetaria can be said to illustrate the night sky instead of accurately reproducing it. But illustrations are known to be a powerful educational tool. Digital planetaria create illustrations that are close enough to create a "willing suspension of disbelief," which means that if I point out Orion it can be recognized as such - and there the fun begins. We can then leave the solar system and observe proper motion, fly through the Orion Nebula, or employ any number of teaching devices that are impossible with an optomechanical instrument.

The last 5 years have seen many pioneering digital dome projects. Lessons have been learned and technologies have matured. The path has now been cleared for digital planetarium systems with advanced features to better realize the promise of the digital dome and to replace optomechanical systems entirely. Greater involvement from planetarium educators is essential in the development of software applications, educational modules and star shows for the digital planetarium if the full promise of this emerging medium is to be realized.