Large Format Digital Cinema: Medium of the Future?

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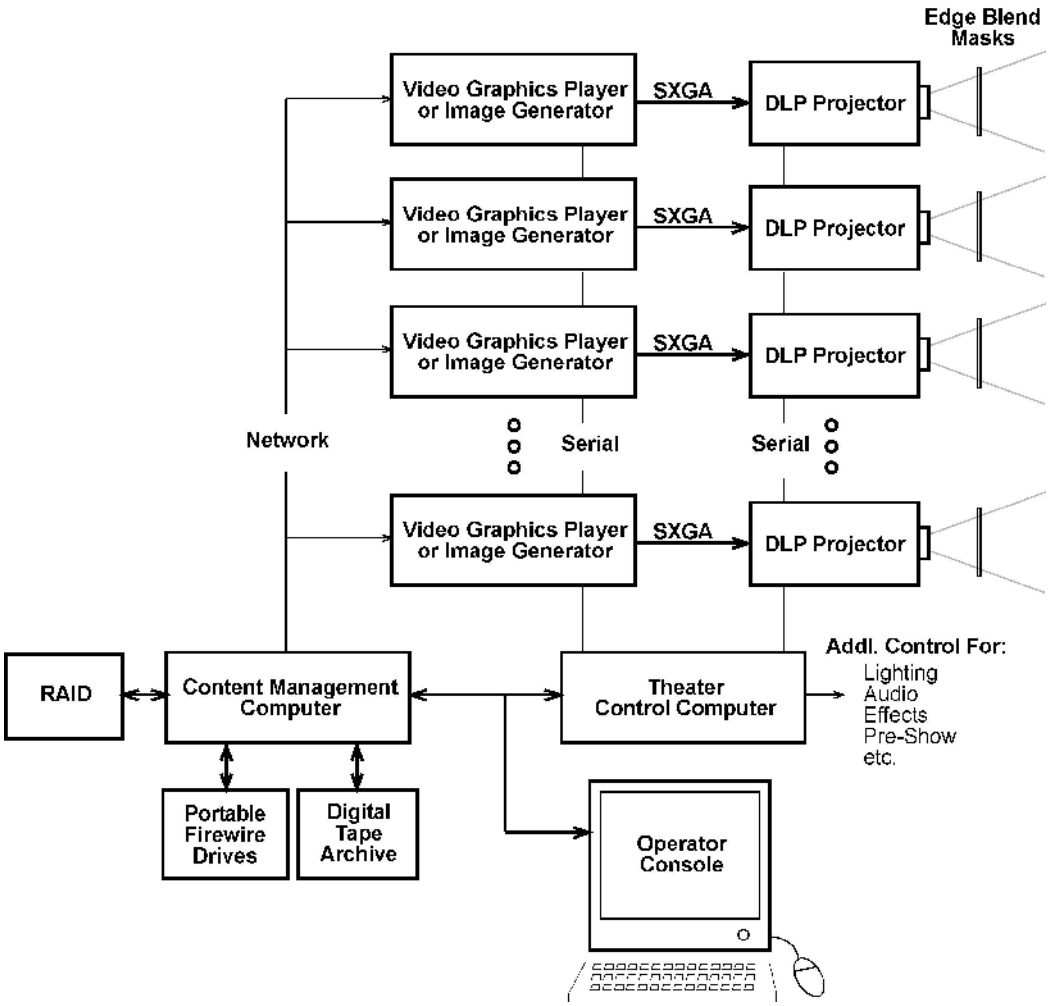
Abstract. The latest developments in large-format digital cinema imaging, playback and projection are reviewed, with an emphasis on real-world immersive theater applications. The latest single-projector large-format solutions are contrasted with existing multi-projector, edge-blended techniques. As with standard 35mm cinema, it is clear that digital projection will eventually replace large-format (70 mm) film. However, unlike the "Hollywood" film industry, the large-format industry is economically and politically more flexible and therefore better positioned to embrace the technological shift to digital. The digital transition promises to open the large-format medium to a greater number of experimental films and student works, possibly leading to a resurgence of interest in the field. However, to date, large-format digital cinema systems have not been used to project live-action films. Large-format immersive cinema is instead developing into a new medium in its own right, with large-format film projection as one of several entertainment modalities. Alternate modes of interest to leisure entertainment include realtime 3D experiences, immersive telepresence, gaming, live video-based performances, and various group interactive paradigms that exploit the unique properties of the large-format medium.

Introduction. The late 1990's brought tremendous interest in the prospect of digital cinema replacing film. Digital cinema allows rapid electronic motion picture distribution, and is free from film artifacts and film wear. Several video projector manufacturers geared up for anticipated sales exceeding 1000 screens by 2002. Today out of 108,000 cinema screens worldwide, less than 50 are digital – far below industry predictions made in 2000. Reasons for this failure can generally be attributed to the size and maturity of the film industry, and to the high cost of digital cinema projectors ($150k USD) compared to standard 35mm film projectors ($30k). The motion picture value chain is deeply segmented – due to antitrust rulings – between film production, distribution and exhibition. While digital cinema benefits the film distribution market segment by eliminating the need to produce and distribute prints, the high cost of the projectors is an excessive burden to the exhibitors. Recent predictions are that digital cinema penetration in the film market will only be 5% by year 2006 [1].

By comparison, the large-format film industry is relatively young and unfettered by the political and economic barriers facing the Hollywood film industry. Large-format films are independently produced, in some cases by the exhibitors themselves. Large-format projectors are already high-cost, low-quantity systems. Recent developments in large-format video projection are now approaching the performance required to reproduce large-format film resolution. In a few short years the large-format film industry will be challenged with a move to digital technologies. While there are a markedly small number of large-format installations (perhaps 350 worldwide), they represent a premium niche for the digital projector industry. And the benefits of converting to digital are amplified by the large-format medium – large-format cameras are much more heavy and bulky than their 35mm cousins, and large-format film is expensive to process, scan and print.

Already there are trends towards digital cinema in the large-format arena – but not where one might expect it. Digital dome theaters and planetaria are currently pushing digital projection technologies to new heights [2,3]. Projector manufacturers, looking for alternatives to the disappointing digital cinema market, are happy to jump into this large-format niche. These "digital domes" have departed from large-format film theaters by exploiting the distinct advantages of digital technologies over film. As such they represent an entirely new medium, with large-format film a possible subset of their overall capabilities. With the advent of high-definition television bringing cinematic quality films into viewers homes, might large-format digital cinema evolve into the destination theater of the future?

Full-Dome Video. Dome video systems were initially developed for tactical military aircraft simulators [4]. These visual systems require simultaneous wide field-of-view and high resolution. This requirement was satisfied by "mosaicking" or tiling multiple video projectors and "edge-blending" them together to form a single ultra-high resolution image. Edge-blended video displays debuted in the planetarium industry in 1997 with the introduction of systems by Spitz, Inc. in the U.S.

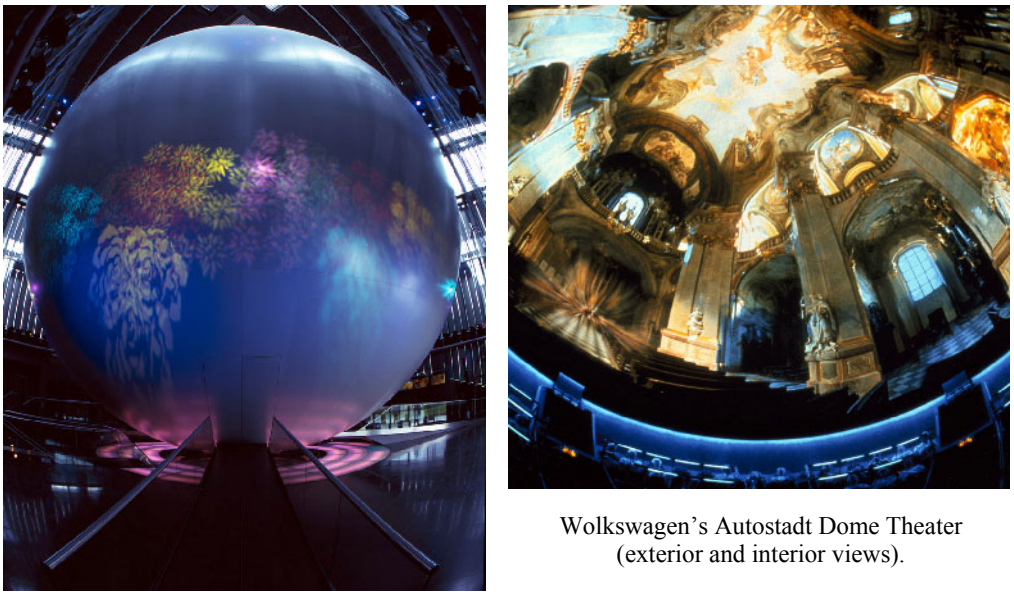


Multiprojector Edge-Blended System

and Goto Optical in Japan. The market has since matured with numerous system providers and a variety of technological approaches.

One markedly different requirement of planetarium systems is the need for high image contrast (i.e. low "video black" levels) to accurately represent the night sky – a more important requirement than overall image brightness. This requirement initially steered the market to embrace CRT projector technologies, which continue to be employed in planetarium and simulator markets despite their virtual disappearance from the mainstream projector marketplace.

There currently exist approximately 50 CRT-based theaters utilizing up to 6 edge-blended CRT projectors to cover a hemispheric screen, including such theaters as the Hayden Planetarium at the American Museum of Natural History's Rose Center for Earth and Space, the Smithsonian Air and Space Museum's Einstein Planetarium, and Philadelphia's Fels Planetarium at the Franklin Institute. When driven by frame-synchronized high-resolution (1280x1024 pixel) image generators or video graphics servers, such systems deliver a (polar) frame size of about 2800x2800 pixels to the dome screen. Image brightness for many of these theaters, however, is well under 0.5 foot-Lamberts (fL), which is perhaps fine for stars but is well under large-format film standards. By comparison, typical large-format dome theaters provide an image brightness of 3-5 fL. Standard 35mm film theaters demand 12-14 fL according to SMPTE standards.



Wolkswagen's Autostadt Dome Theater
(exterior and interior views).

Dome systems based on DLP (digital light processor by Texas Instruments) projectors debuted in 2000 with the Spitz/Furneaux-Stewart design for Volkswagen's Autostadt theater. This system utilizes four Barco DLP projectors, each projecting 12k lumens onto a 14.7-meter diameter dome to yield film-quality brightness of 3.5 fL. To achieve greater resolution, DLP-based theaters are now being designed with up to 11 edge-blended projectors. One advanced system under construction is the planetarium at Papalote Museo del Nino in Mexico City. This theater will have 9 edge-blended Barco DLP projectors to provide a 3200x3200 pixel image and brightness exceeding 2 fL on a large 23 meter dome screen.

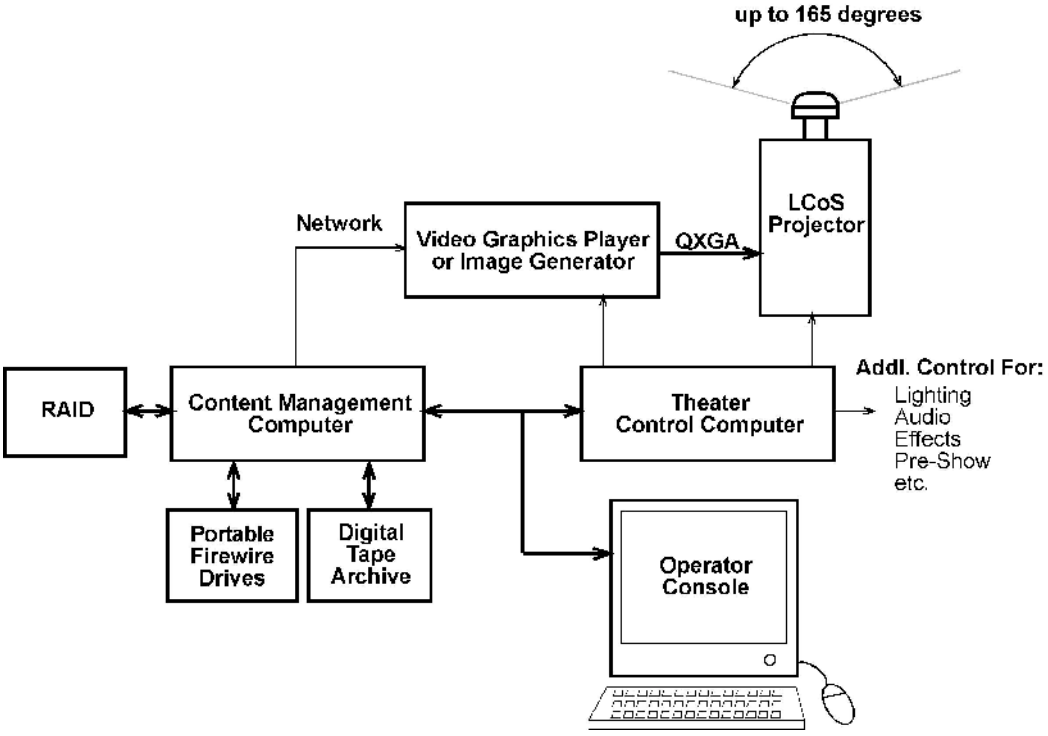
Such systems must utilize fixed optical masks for edge-blending to ensure that the "video black" level (actually a visible grey due to the limited contrast ratio of 1600:1) is seamlessly blended. The highest resolution DLP-based system recently opened at the Denver Museum of Nature and Science's Gates Planetarium with 11 Barco DLP projectors providing a 3600x3600 pixel image delivered by an 11-pipeline SGI Onyx® 4 realtime computer system.

Multi-projector implementations allow brightness and resolution to be scaled up by adding more projection channels. The obvious disadvantage to multi-projector systems is increased complexity and maintenance requirements. Future systems will likely employ automatic display alignment using image processing technologies for both flat-screen and dome applications [5]. However, newer single-projector systems are emerging that promise to simplify large-format digital cinema systems, thereby opening their use to a wider market.

Single Projector Systems. The latest entry into the large-format video arena was made possible by JVC's new QXGA resolution projector utilizing liquid crystal on silicon (LCoS) technology. With 2048x1536 pixel resolution, near-cinematic resolutions can now be achieved on a dome using a single projector and lens. While the image resolution is at the low end of the large-format display spectrum, it is equivalent to the master resolution used in the Omnimax feature films *The Magic Egg*, and *We Are Born of Stars*, produced in the mid-1980's (2000x1500 and 1732x1280 pixels) [6]. Single-projector solutions are much more reliable, easier and less expensive to maintain than multi-projector edge-blended systems. This is of particular importance in developing countries where highly skilled technical labor is scarce. Brightness of off-the-shelf QXGA resolution projectors is currently limited to 7000 lumens, but advancements are already underway in both brightness and resolution.

The future is bright for large-format projection systems. Texas Instruments recently demonstrated a 2k resolution digital multimirror device (DMD) that will soon be adapted into digital cinema projectors. Digital Projection, Inc. has long been working towards a large-format DMD-based projector that will likely employ TI's new 2k device. JVC has already demonstrated Quad-HDTV projectors with 4k x 2k resolution. And the grating light valve (GLV) by Silicon Light Machines promises resolutions exceeding 4k x 4k using semiconductor-based laser light sources [7]. The GLV is capable of very high brightness projection due to its high damage threshold. GLV technology could well dominate future

large-format digital projection systems, provided that laser eye-safety issues for free-space projection can be adequately addressed.



QXGA Resolution Single-Projector System

Digital Dome Applications. While the latest digital dome video systems now approach large-format film quality, actual transfers of large-format film to the digital medium are scarce. Instead, these theaters run programming that is almost exclusively based on 3D animation and 2D compositing effects. Perhaps the science theme prevalent in most digital dome theaters best lends itself to 3D animation rather than live action. After all, where can one shoot a time-lapsed galaxy formation sequence, or capture a live-action fisheye flythrough of the human body? Also, digital scanning of large-format film is expensive, costing several US dollars per frame. Digital dome show budgets range from $100k to $3M USD, just a fraction of the typical $6-8M budgets for the large-format film medium. It costs several thousand dollars per minute simply to develop exposed 65/70mm film.

An interesting community has emerged around large-format digital domes. Unlike large-format film, the digital medium is highly accessible. Despite the large frame size, shows can be affordably produced using desktop tools and a modest PC render farm, and immediately transferred to the big screen for preview. Shows can also be easily updated to reflect current events, or syndicated features can be automatically downloaded on a periodic basis over a high-bandwidth network connection (such as a “sky tonight” program for planetariums).

A number of theaters have been producing original content, including the American Museum of Natural History’s Hayden Planetarium, Houston Museum of Natural Science’s Burke Baker Planetarium, Salt Lake City’s Clark Planetarium, Denver Museum of Nature and Science’s Gates Planetarium, the National Space Centre in Leicester, UK, University of Louisville’s Rauch planetarium and more. Student projects have been pioneered by University of New Mexico (in conjunction with Albuquerque’s LodeStar Astronomy Center) and Drexel University (in conjunction with Spitz, Inc.). In addition, quality full-dome productions are available from Spitz, Inc., Evans and Sutherland, Sky-Skan and other vendors. Shows are distributed in pre-rendered “dome master” format, an equidistant polar mapping that has become industry standard. Dome master resolutions vary from 1536x1536 for fisheye systems, 2200x2200 for “standard” resolution, and up to 3600x3600 for very high resolution displays.

In addition to pre-rendered playback, several types of interactive full dome systems are now available. The simplest form of interactivity utilizes pushbutton responders in conjunction with interactive polling for pre-rendered show branching. Realtime 2D compositing allows realtime keying (via alpha masks) allowing, for instance, a starfield to rotate in realtime behind a panorama or other foreground objects. Realtime 3D rendering offers the ultimate in control, allowing interactive flythroughs of datasets, interactive gaming, near-realtime imaging (i.e. manipulating images of audience members on the screen), and telepresence (realtime immersive imaging). Relatively inexpensive PC clusters using commodity 3D graphics cards are placing realtime 3D systems within the reach of many theaters. Cross-platform show transfer standards for realtime productions do not exist, however, limiting realtime shows to their proprietary hardware platforms.

Group interactivity with realtime 3D productions has primarily relied on 5-button responders. Other interactive paradigms include interactive wands such as the Cinematrix® system, but such systems have failed to gain widespread acceptance to date. While the jury is still out on the effectiveness of direct audience interactivity with realtime 3D simulations and datasets, the value of realtime for live operator interactivity is unquestioned. Planetariums in particular have long been accustomed to instant control over the night sky without time-consuming rendering. Extensive 3D databases now extend this instant navigable control to accurate models of the known universe, the human body, ancient sites and more. In addition, realtime control can accelerate 3D show production by providing instant rendering and interactive manipulation of animatics. Rapid updating of shows is also facilitated by realtime systems. For instance, newly released NASA texture maps of Mars can be inserted into an existing show on the red planet without re-rendering and re-editing the feature.

Perhaps one of the most exciting - yet virtually unexplored - applications of realtime 3D systems is its potential use in live video art performances. Unlike the abstract laser light shows of days gone by, immersive video performances can offer rich, full-motion shaded graphics with numerous special effects. Digital dome theaters are just beginning to explore the artistic use of this powerful medium. When leading VJs (video jockeys) discover the digital dome there will be no turning back.

Conclusion. Large-format film is a growing medium with nearly 350 theaters worldwide. As HDTV brings cinematic quality films into home theaters, large-scale immersive theaters could well become the next location-based cinematic medium by providing unique experiences not yet available in the home. Digital dome theaters are currently pioneering large-format immersive digital cinema using cutting-edge projection and playback technologies. Digital domes are, in the process, becoming a new medium in their own right. Digital domes are more than planetariums, and more than film theaters – they are portals into cyberspace, virtual environments, and the new world of electronic information. As an artistic medium, they are perhaps the closest thing yet to crawling inside the artist's head, since they allow artists to freely express themselves using a powerful medium that truly immerses their audience.

We invite those interested in exploring this new medium to join us at SIGGRAPH 2003 this July where we will, for the first time, showcase the latest full-dome productions at the Reuben H. Fleet Science Center's IMAX® Dome theater, using Spitz's ElectricSky® II full dome digital projection system, as part of a full-day course on the subject [8].

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