The Future of Fulldome

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Abstract. Fulldome is the term given to immersive theaters and spaces where images are displayed on a dome shaped screen. Born out of the need of Planetarium theaters to project video images of astronomical data, Fulldome is rapidly becoming a new media environment used to present scientific data, entertainment shows and unique live presentations. This paper is a technically orientated perspective of the current and future trends of Fulldome within a five year horizon.

The more it changes...

Like the classic saying, "the more it changes the more it stays the same" this too applies to Fulldome; particularly with respect to the display technology. The factors that drive Fulldome display choices are common across large format displays. In the early 1980's, CRT projectors dominated the large screen market (although large is relative of course; screens of 2 meter width were considered large at that time). An emerging alternative came from videowalls typically comprising an array of large (28") monitors. By stacking monitors in 3 x 3, 4 x 4 or even larger arrays, bigger higher brightness displays could be created. By 1992, very large displays were built using this approach culminating in the World's biggest 850 monitor videowall at Expo in Seville.

By then, the first high brightness LCD projector was launched with 1,000 lumens and VGA (640 x 480) resolution. This, many thought, spelled the end for making big displays out of many smaller ones as projectors would only get brighter and more resolute. So it did, and so it continues. But with it, so did the insatiable appetite for larger screens and more resolution. So instead of these higher resolution brighter projectors stealing market share from the multiple monitor/projector displays, they simply served to make 'bigger and better' even easier. With the explosion in flexible format, multiple projector arrays, came a wide range of devices for controlling them, and for generating and distributing the many pixels across the display for image blending, signal conversion and formatting, picture-in-picture windowing and other pixel processing features.

So what of Fulldome? It has certainly benefitted from the driving demands of other markets. As projector performance increases and prices drop, affordable performance is within reach of many theaters. But is it enough? Have we yet reached a satisfactory level of performance so that we can now use the reducing costs of technology to free up budget to invest in much needed quality content? Well if all the other display markets and the trends in the last twenty-five years are anything to go by, the answer is most likely not!

The Display System

Display system – technology.

Various display technologies are employed today to create Fulldome images. They fall into two main categories;

- **Light valve projectors.** Light valve projectors use a fixed light source (lamp) and a set of optics to focus light onto a single or multiple imaging device (multiple devices are used to improve color performance or contrast). The imaging devices modulate light via a fixed array of reflective (DLP™ or LCoS™) or transmissive (LCD) pixel modulators.

- **Emissive scanned projectors.** These projectors typically use the same technology to create light, and to modulate the image. CRT projectors fall into this category (which are now almost obsolete) as do some versions of laser projector. A beam of light is created which scans across the video frame whilst at the same time being modulated to create each pixel.

Both solutions rely upon a reflective dome surface to create an image. The gain (reflectance) of the dome surface has a significant impact upon image performance, both in terms of brightness (luminance) and contrast.

A significant factor for Fulldome technology is that it is unlikely that the market itself is able to support the development costs and sustain the ongoing development of any dedicated technology. It will therefore have to rely upon developments targeted for other applications, and adapt them for use in the dome. These applications will include uses where image fidelity is important; such as home cinema, digital cinema and simulation. Light valve projectors, because of their use across a range of markets, are the most cost effective and mature technology in use today.

Other existing technologies and near term developments may well be suitable for Fulldome use. Much is talked of LED domes for instance. LED is an emissive technology which already offers a broad color gamut (saturation), contrast, and light output. They also have excellent life (tens of thousands of hours) and stable light performance over time. LED displays are a direct view technology and could be applied in such a way as to minimize scatter (light cross bounce in a dome). However, to get the necessary resolution and fill factor (gaps between pixels) to compete with projected solutions along with suitably graded LED's (individual LED's vary significantly in performance, to get a consistent display they are factory graded which is a costly exercise), the price is likely to continue to be prohibitive for the foreseeable future. Other interesting projector technologies include laser scanned light valves. These use a laser to create the light source, and work with conventional imaging devices to create the picture. Another option is the LED projector, which simply uses LEDs for the light source. Both approaches promise a very stable, long life light source and a broader color gamut.

Display system - resolution.
Using multiple projectors, it is becoming relatively cost effective to produce Fulldome display systems (360 degree by > 160 degree field of view) of between 16 to 18 pixels per degree (3k x 3k) to 22 to 24 pixels per degree (4k x 4k). Those with a higher budget could consider a range of the latest 4k resolution projectors to get close to 50 pixels per degree. All of these solutions require more than one projector and with it, a solution for edge blending, projector calibration, and ongoing maintenance.

Single projector solutions for smaller domes are in use today, typically running a maximum of 5 to 6 pixels per degree (1k) resolution. As 4k projectors become more cost effective in the next few years, single projector, small domes will be able to make the leap to 10 to 12 pixels per degree. However, they are likely to lag multi-projector resolution by a factor of four until such time as the chase for more pixels abates (which could be a while if the past is anything to go by).

8k resolution (8,000 pixels x 4,000 pixels) LCoS™ imaging devices have been shown in prototype form already. Expected to be on the market in the next two to three years, this format will again raise the expectations of the market and of the audiences of the future.

Display system - brightness.
A topic of some debate. For many years, brightness of a dome has been an issue, primarily due to the use of CRT projectors which have very low brightness (by today's standards, yielding only a few hundred lumens versus many thousands possible with light valve projectors. Also, as CRTs use a scanning beam, they can create relatively bright spots of light such as stars, but when needed to illuminate the whole image area for video content, the brightness falls significantly). The typical luminance of a large Fulldome theater (say above 18 meters) with a CRT projector would be less than 0.5 ftL (foot lamberts), and sometimes as low as 0.1ftL. Today

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it is quite common to exceed 0.5 ftL, and as much as 1ftL or more with light valve projectors. Those familiar with the cinema industry will expect 8ftL or more, but the environment is quite different because of the light scatter created in a dome and after all, due of the way the human eye works, brightness is relative. Of more importance is contrast. A dome with 0.5ftL with a high contrast will look significantly better (and even brighter!) than one with 1ftL and low contrast.

Display system – contrast.
It is important to understand the various criteria that contribute to system contrast in a dome. The first is the projector contrast, typically quoted as sequential contrast (the ratio of a brightness of a full white image divided by that of a full black one). Sequential contrast ratios are improving all of the time. Conventional light valve technologies are in the range of 2,000:1 whilst optimized projectors are now exceeding 10,000:1 and approaching 30,000:1. Dedicated ultra high contrast projectors using extra modulation stages or optimized optics have been launched recently. These projectors have a sequential contrast approaching and exceeding 1,000,000:1. This new benchmark for sequential contrast will continue to increase over the next few years, with figures possibly exceeding 5,000,000:1.

The second contrast factor is the ANSI contrast ratio of the projector. Rarely quoted, this is a standard measurement technique using a checkerboard test pattern (a 3 x 3 array of black and white squares) and measuring the average white level and dividing by the average black level. This method takes into account the optical path of the projector and its ability to minimize internal scattered light. The light from the white areas of the image will contaminate the black area to various degrees. The lower the internal scatter, the higher the ANSI contrast. Figures well below 100:1 are typical, higher than 150:1 is very good.

The final contrast factor is the dome screen itself. By its very nature it's a 'light scatter machine' - bouncing the projected light in all directions; mostly back to itself! When fully lit up, the system contrast falls dramatically into single digit figures. Using the same checkerboard measurement process that is used for projectors, dome system performances can be compared; anything above 8:1 is very good. So unlike almost any other display system, contrast in a dome varies massively with content; anything from 10:1 (a bright video scene) up to 1,000,000 (a starfield) if the projector is capable.

In summary, display system resolution is likely to continue to rise as a direct result of the increase in native resolution of projectors. 100 Million pixel domes are foreseeable at the high end with multiple projector solutions. Smaller domes will be served either by single, high resolution projectors, or by two, three, or four projector solutions using lower cost products supported by automatic alignment systems dealing with the need for image matching as the lamps age.

Brightness will start to plateau at between 0.5ftL and 2ftL, as the need to optimize contrast will drive screen gain down (trading brightness for much needed contrast), until a revolution in screen technology comes about.

Stereoscopic Projection.

A recent trend in Fulldome systems is to employ stereoscopic (3D) projection. The technology exists to produce, store, and project 3D images in a dome, and by wearing suitable glasses (to match the technology employed), the audience can experience a more immersive show. Particular care needs to be taken when producing and presenting 3D content in a dome to ensure that the move to 3D results in a better experience than that achieved through use of good monoscopic content in a good quality dome. The fundamental trends of resolution, brightness and contrast apply equally to 3D domes, however 3D tends to be more tolerant of low resolution, has a significant (negative) impact on brightness and is more expensive in hardware and production. The paper "3D demystified" [1] goes further to explain the technologies and considerations for 3D in a dome.

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Compute and Image processing.

Producing Pixels.

To drive these high resolution environments, high performance computing platforms are typically employed using hardware graphics engines developed initially for HPV (High Performance Visualization) applications, and more recently for the gaming industry. Parallel graphics channels are used to increase performance where typically a graphics pipe (computer and graphics card) will be dedicated to serve a single projector. Dual headed (or even quad headed) machines can be used to serve more than one projector for simplicity or cost reduction. However, with the increasing demands of software applications to run in the theater, care should be taken to allow for sufficient graphics processing power for the future.

Images are either generated in real-time (in the same way that a computer game works) or are pre-rendered (like a DVD). Real-time applications need some storage for the data to be processed and are very demanding on processor power. Already today, data can be streamed live from the internet (or another data source) to be processed for display onto the dome, and these domes can be connected together to show common data, using remote presenters to steer the journey concurrently across multiple theaters. This trend is likely to continue pushing the demand for high bandwidth data pipes into the theaters. An important advantage of real-time systems is that they can easily generate content in the native resolution of the display - so as display resolution increases, so will the content resolution from a real-time system.

Pre-rendered content typically plays from either a computer hard drive or an array of hard drives. Certain image compression techniques can be used to reduce the file storage size and the pixel throughput capacity, and are likely to be used for mid to low end systems to optimize budgets. Image fidelity will become increasingly important as advances in Digital Cinema raise the benchmark for audience expectations. Uncompressed playback will become the benchmark; image bit depth will increase from 8 bit (16 million colors) to 10 bit (1 billion colors – about 1 billion more than 8 bit!) and image frame rate will move from 30fps (unique new image frames per second) to 60fps, reducing motion artifacts as images are panned across the dome. Using technology developed for data intensive applications, hard drive arrays can be configured for massive storage for varying the high pixel throughput required for high resolution domes. The production budget increases significantly as dome resolution, frame rate and bit depth increases. New software tools and production workflow methods are evolving to reduce the time cost of production, data storage is constantly becoming cheaper and larger (Terabyte drives are already with us), and higher resolution cameras will become more commonplace.

However, production at 4k x 4k resolution is expensive, and with a shortage of good quality content in the market at present, production costs need fall in the short-term.

Multiple Sources.

Already it is becoming increasingly common for a Fulldome theater to have more than one Fulldome source. As the range of potential uses for the dome expands, so does the need for flexibility and enhancements. Each vendors software product offering will have its own attributes for instance; collaborations with the education sector or commercial organization will dictate the use of a particular piece of hardware or operating system. Experimentation or back-up systems will be added; each of these reasons giving rise to the requirement for more than one Fulldome source (computer or computer cluster). At the high end, there are already a number of Fulldome systems that use two or more computer clusters.

To accommodate this need for flexibility, the display system needs to be able to handle multiple inputs (much like a Home Theater system), and ideally integrate them in such a way that they are easy to interoperate and are seamlessly presented to the audience. It's possible today to integrate sophisticated image processing electronics to handle multiple computer clusters, cross fading between them, and inserting high resolution video windows around the dome (much like a giant video mixer). This 'multimedia' capability will increase the potential uses for Fulldome theaters in the future.

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Sound

Multichannel systems are an essential component of Fulldome. To support the high field-of-view of the display, the audio system should be able to place sound in a logical position with respect to the objects in space - this can (and should) even include below the screen, and even behind and below the audience (as objects move in and out of scene).

Standard configurations include 5.1 and 7.1 systems (for unidirectional seating) where the two extra channels in 7.1 are arranged for the vertical axis. Theater specific configurations are commonplace, employing more channels (more than 20 in some cases). Particularly in dome theaters, the approach of using a higher quantity of lower volume speakers is preferable to employing a lower quantity of higher power ones. This approach gives greater coverage with less 'hot-spots' - particularly for audiences seated towards the edge of the theater.

Recent developments and deployments in fully spatialized sound systems are making their way into Fulldome. This technology makes it increasingly possible to move sound tracks around the dome in three dimensions, to follow the visuals - creating a more realistic experience.

Interactivity and other enhancements

Interactivity has been deployed in theaters for a number of years, either by fixed buttons or joysticks located in the seats, by wireless clickers, by fully interactive wireless handsets or even colored hand held paddles, and by image recognition cameras.

Unfortunately, few examples exist of successful, sustainable implementation, and use of interaction in a theater. The technology is certainly not the bottleneck. Until very recently, the mass market computer interactive device has been the keyboard and mouse – not very appropriate for a theater.

Hopefully the recent introductions of new mass market user interfaces such as the iPhone™, the Wii™ and Microsoft Surface™, will change the public perception of computer interaction; bringing about a range of opportunities to reintroduce interaction in Fulldome.

Interestingly, the most successful human computer interface in a dome to date is another human with a microphone; one who is knowledgeable in the subject being presented. Long may this continue.

Conclusion

For the last 10 years the Fulldome market has been early adopter territory, with plenty of successful implementations (along with a number of unsuccessful ones). Recent signs are that the market is slowly approaching a mature stage, and although leading and bleeding edge technologies are still being showcased, there are plenty of installations using more mature and proven technologies. This maturity brings about operational robustness (essential for public theaters), price reductions, market consolidation (a smaller number of better vendors), and proven business and operational models for theaters. Hopefully the desire to have the very latest technology will be balanced by the wisdom to ensure that it is dependable, and sufficient funds are reserved for the content. As the market starts to stabilize over the next few years, the opportunity to improve the quality and quantity of content and presentations for these theaters will increase, and will allow Fulldome to be recognized and accepted as the new and viable medium that it promises to be.

References

[1] Howe. M, "3D Demystified" *IPS 2008 Fulldome Summit* Chicago, July 2008.

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