“A way to define the space in such a way that software could be added as a plug and play. This is a function of the software and providing a common definition of the physical space.”

Multiple test patterns to perform multiple functions:

→ Alignment (CRT only?)
→ Scaled registration
→ Sub system test patterns (audience response, navigation, tracking)
→ Residual Error (specific for a projector / bend system)
→ Black Balance / Color balance

→ Users guide with test patterns so that non-engineers can correctly define issues

→ It is very easy to have a technical success and a market failure.
→ If the standard is not supported it doesn’t matter.
→ “Vendors who want to play seriously stand behind their products to help customise the solution and provide good customer service for a lasting relationship. Our project needs stable partners with upgradeable technology.”
→ “Symbiosis is not working well, but there is no reason for this other than the lack of industry standards. The viewing public would be best served, and so would industry, if greater efforts were made to respond to our needs.”
→ “The one area of this institution that does not need biodiversity is the technology”
→ “Exchange of knowledge, means exchange of content.”

→ Format noun the way in which something is arranged or set out:
→ The medium in which a sound recording is made available:
→ Computing a defined structure for the processing, storage, or display of data: a data file in binary format.
→ Guideline noun a general rule, principle, or piece of advice.
→ Standard noun 1 a level of quality or attainment:
→ A required or agreed level of quality or attainment:
→ 2 an idea or thing used as a measure, norm or model in comparative evaluations:
→ adjective 1 used or accepted as normal or average:
→ (of a size, measure, design, etc) such as is regularly used or produced:
→ Care required – do we mean noun or adjective!
→ Standards are critical
→ Methodology is a means to an end
→ Standards can shape the market place
→ Good Standards do not inhibit innovation
→ There are competitive issues involved in standards
→ Standards reflect the culture
→ Standards
→ Formats
→ Guidelines
→ Recommended Practices
FullDome Standards Summit

The Past, Present, and Future of Full Dome, Full Color, Single Projector Digital Planetariums

Presented by Philip Groce

With the greatest respect for all of the participants at this summit, I consider this event a great act of professional optimism. The track record for establishing technical standards in the planetarium industry is, at best, dismal.

“The audio-visual technologies with the largest installed base outside of the planetarium field will determine the technical future and standards of planetariums.”

Technical Issue #1: Full Dome Standard (Portability from one theater to the next)

Technical Issue #2: Resolution and Image Quality/Brightness

The large-format film industry has adopted 10 to 12 foot-lamberts for flat screen projection and 6 to 8 foot-lamberts for dome projection. Not one of the digital fulldome systems demonstrated to date comes close to the large-format film standards for brightness, which is why they all look pretty dreadful when trying to project a daylight scene.

As a practical matter, manufacturers of digital dome systems should stop listing the ANSI Lumen brightness of the projectors. It means almost nothing. What matters is how much light reaches the dome (incident lux) and how much is reflected back by the dome screen to audience (foot-lamberts).

The other useless and often deceiving specification offered by manufacturers of fulldome digital systems is “contrast ratio.”

The reflectivity and resulting light cross-bounce of the dome is also a very large factor in the apparent contrast ratio. For this reason, we need to standardize maximum reflectivity for fulldome projection. Experience has taught me that the contrast and color saturation of all digital dome images greatly deteriorates on domes with more than 48% reflectivity. Currently, we have Medial globes on 6.1 meter domes as dark as 24% reflective. The general rule of digital domes is “the darker, the better”. The perfect planetarium would be brilliant projection onto a nearly black dome. At that point, the projected sky would look like the real sky, and fulldome panoramas/all-skies would suspend the disbelief of the most ardent skeptic.

Technical Issue #3: Image Consistency/Stability, Seam Visibility
Technical Issue #4: Effects of Theater Geometry

In planning productions, there should be a “safe area” dome original for critical action, information text and credits:
- 1000 pixels for 1024 systems
- 1500 pixels for 1536 systems
- 3125 pixels for 3200 systems, and so on.

We may consider reducing these “safe” dome originals even more to allow for smaller than 180 degree dome sections. Dome sections between 160 degree and 180 are becoming commonplace in today’s planetarium theaters. Reducing the safe area of dome originals will allow more digital content to play without rerendering or geometry correction.

Philip Groce

Standard for theater description, What is a theater?  Dan,
**Summit** with subsequent dissemination of the resulting technical papers. In addition to helping guide the Black Hole Project planetarium show distribution, the summit was the first ever technical conference on fulldome planetarium technologies.

Spitz Inc. performed a set of production tests to help ensure wide distribution and cross-compatibility of future shows with many different display systems. While there are many issues that need to be considered when attempting to ensure wide distribution, Spitz chose to deal specifically with issues that are fundamental to the production pipeline and must be understood before show production can begin. The goals of the tests were to:

- establish action and text safe areas for fulldome production,
- investigate how to deal with differently tilted domes,
- investigate how to deal with gamma issues, and
- address what happens to stars when transferring content to systems with different resolution requirements.

Most of the issues investigated involve production aesthetics and are not empirically testable. In these cases, the testing methodology employed a series of graphical tests screened by a small team of aesthetically trained viewers who utilized a collaborative consensus approach to converge on a recommended “best practice.” Only theaters with unidirectional seating designs are addressed in our research.

**Nominal Camera Tilt.**

1. Visible horizon – a sequence where there is a clearly visible horizon, such as a landscape.
2. Non-visible Horizon – A sequence where there is no visible horizon line and no camera motion that might imply a vector-based horizon. An example might be a scene in outer space where the camera is not moving.
3. Implied Horizon – A sequence where there is no clearly visible horizon but a horizon is implied, either through a camera motion vector (camera dolly) or perspective vectors (vanishing points). This could be a space-based scene where the camera is moving forward past objects such as planets or asteroids. The more objects that we are moving past, the more clearly defined the implied horizon will be.
4. Rolling Text plane – This would be a simple credit roll, rendered out on a billboard plane. The reason for this test is to see how the tilt affects the readability of text.

An alternate approach was suggested for ensuring a gravity level horizon in the most number of theaters that involves over-rendering the field of view and then post processing to the proper dome tilt. In other words, if you change from rendering a 180 degree polar master to a 210 degree polar master, you could then do a post process to crop out 180 degrees from the 210 degree master and simultaneously apply an additional tilt factor. The disadvantage of this method is that higher resolution masters would be required in order to maintain image quality.

**Action and Text Safe Areas**

As fulldome video producers, we too can benefit from a defined action and text safe area guideline, but for different reasons. Our problem is not that the edges may get cropped in projection, but that since the field-of-view that we have available is so wide, it’s possible to place important information...
beyond of the field-of-view of the viewer. It’s possible to make text so large that it’s illegible or to frame action over such a large
Black Hole Project – Spitz Sub-Award Final Report 4
area that it becomes difficult to follow. The goal of this test was to create a “Dome Master” format reference frame that shows recommended title and action safe areas.

**Gamma.** Gamma is a paper topic in itself and only a broad overview of the issues are given here. In our discussions with various content producers, projector manufacturers, and theater operators, we realized that when people refer to gamma, they are often referring to far more than just gamma. They are actually talking about gamma, color
Black Hole Project – Spitz Sub-Award Final Report 5
temperature, white point, black point, and basically everything to do with accurate representation of the source material on the dome. This is the most challenging of all the tests because ensuring accurate color representation requires proper calibration of every system in the imaging pipeline, from creation to projection

Since the slicing/splitting process is unique to each theater, we conclude that this is the best point in the production chain to perform gamma adjustments. Spitz’s Polydome dome-master slicing software has the ability to slice and correct gamma at the same time. Our group agrees that this should be a standard feature of all slicing software

**Star Decimation.** Different types of theaters have different resolution limits. Most high-resolution imagery can be scaled down and played back on lower resolution systems with only the expected penalty of a corresponding loss of fine detail. Unfortunately, stars and starfields – the staple of planetarium programming – fall into the realm of “fine detail.” The conundrum is that, if a production is rendered at high resolution with very fine stars, those stars might be super-sampled out of existence during the scaling-down process for theaters with lower resolution limits. If the stars are rendered large enough to survive the scaling down process, then they may look too large and fuzzy when projected on systems with higher resolution capabilities. The purpose of this test was to investigate what happens to very fine stars during the scale-down process and how to best deal with that issue.

**Recommendations for Black Hole Project**

**Dome Master Format and Size.** Dome master frames should be rendered at a minimum of 3600x3600 pixels in an equidistant polar format. Rendered stars should have a half-intensity width of 4 pixels. Frame number and copyright should be placed in the lower RH (NCSA uses the Low. Left) corner of the frame. Recommended file types include TIFF and TARGA with RLE compression, or other lossless compression format compatible with distributor’s system. Image should be oriented such that the bottom of the frame represents the front-bottom of the dome screen, and the right and left hand sides of the master correspond with the respective right and left sides of the dome to a viewer sitting at dome center within the theater.

**Camera Tilt.** Nominal fisheye camera tilt should be 15 degrees from vertical.
Safe Action Area. Recommended safe action and text area is the region approximately defined by +/- 50 degrees longitude (measured from dome front/center), and ranging from 10-60 degrees latitude (altitude).

Audio Format. To accommodate for variations in sound systems in different venues, the original digital "stem" tracks and project files must be available for re-mixing or encoding for individual venues. A "generic" 5.1 mix is derived from these files as well as a number of odd formats such as 16.1. It is preferable to re-mix the sound in each venue when possible utilizing a portable editing system. It is recommended that program soundtracks should be made available in (minimally) stereo and/or 5.1 surround formats. Audio shall be formatted as 16-bit, 48kHz .wav files.

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Two versions of each soundtrack should be prepared: one that is timed for synchronization with 29.97 video and another that is timed for systems that use 30fps for video playback. Audio shall be provided as discrete mono channels, so that the show distributor may properly format/encode the soundtrack for the requirements of the specific playback system. The following naming convention shall be used:

5.1 Format Soundtrack
USE FILENAME CHANNEL
required filename_FL.wav Front Left
required filename_FR.wav Front Right
required filename_LR.wav Rear Left
required filename_RR.wav Rear Right
required filename_LoCter.wav Center
required filename_LFE.wav Low frequency signal (Sub-bass)

Stereo Soundtrack
USE FILENAME CHANNEL
required filename_FL.wav Front Left
required filename_FR.wav Front Right

Work-flow issues; such as nomenclature, archiving and sharing digital content.
- Scenic design for the dome environment,
- Designing for the greatest content comprehension in a VR environment.
- Preview and verification processes for visuals and scripts.
- Formative testing during show development and creation.
- International / Universal show design and language.
- Design for greatest audience experience and satisfaction.
- Legal standards and templates for contracts and copyright issues.
- Acquisition and manipulation of live action footage for the dome.
- Vocabulary used by a distributed production team.
- Scientific accuracy, crediting and verification.
- Transitions, motion, editing, & "framing" for fulldome,
- Designing in the "viewer oriented" VR environment, the personal experience.

Potential or proposed fulldome industry standards
- Industry guidelines or “best practices”
- Standard nomenclature or terminology
- Standardized test frames or sequences
- New technologies that will affect standards efforts
- Methods to facilitate cross-platform show distribution
- Areas benefiting from greater vendor cooperation
- IPS support for standards and technological exchange
- Philosophical discussion of standards issues

A Fulldome Standards Summit was organized and held as a special session at the International Planetarium Society (IPS) 2004 conference in Valencia, Spain. The Summit was held on July 7 & 8 at Valencia’s Ciudad de las Artes y las Ciencias, concurrent with other IPS conference sessions. Summit co-chairs were Ed Lantz of Visual Bandwidth, Inc. (www.visualbandwidth.com) and Ryan Wyatt of
the American Museum of Natural History’s Rose Center for Earth and Space (www.amnh.org).
Wyatt and Lantz secured permission from IPS 2004 to hold the Summit, and published a Call for Papers (linked to the IPS website) that resulted in 13 excellent quality technical and informational papers related to fulldome standards.

General standards are proposed for specifying fulldome displays. Proposed specifications include brightness, brightness uniformity, color uniformity, contrast, resolution and update rate. A methodology for measuring edge-blend uniformity is proposed, and suggestions are made for approaching more difficult parameters such as color gamut

“The Flight of the Pixel”
“Proposal for Dome Standards”
By their very nature, Digital Domes are Pixel centric environments. Their performance and capability dictated by the hardware and software used to generate, distribute and ultimately display each and every pixel in the system. “The Flight of the Pixel” follows the journey of a Pixel from content to eye to describe the core principles that apply across the range of solutions in an attempt identify the key considerations for standards relating to large screen spherical displays.

Benjy Bernhardt, American Museum of Natural History
“Audio Standards That Aren’t”
In the film industry THX sound describes a quality assurance program for audio systems rather than an audio format. This simple set of standards and practice allows for reasonably faithful audio mix reproduction in theatres around the world. Digital Planetaria have largely adopted 5.1 as an audio track format, but generally have no meaningful standard as to the placement, power balance, and equalization of the speakers. A short description of the difficulties this situation has created in porting content will be presented, along with some possible approaches toward achieving more consistency in sound system design. Some strategies for spatialized mixing and mix portability will also be discussed

“Sound and Video Production Solutions”
AllSky video shows currently represent a growth market and it is urgent to propose a format meeting all requirements. R.S.A. Cosmos, as a European player in the AllSky video shows market and manufacturer of a complete AllSky digital planetarium solution, wishes to participate actively in this elaboration by defending some European specifications, such as frame rates. What are the specifications of the projection system to
Black Hole Project – Spitz Sub-Award Final Report

Show Distribution Medium. Dome master video frames and audio content should be delivered to Spitz on external PC-formatted (NTFS file system) 6-pin, Firewire drives. Video should be organized into folders according to frame numbers, typically with a maximum of 10,000 frames per folder. Audio
should be organized into a 29.97fps folder and a 30fps folder, with sub-folders for stereo and 5.1 surround mixes.
consider to create a standard exchange of AllSky video shows? Fish-eye images have been adopted as standard by the community, so it is important to define how to obtain them, their resolution as well as a working chain allowing to the planetariums to use them. The fish-eye image rendering method will also have to meet the requirements of planetariums that produce videos according to their technical, temporal and financial means. What method should be used to produce fish-eyes? What resolution should be adopted for these images? What method should be used to adapt them to a particular planetarium theatre?

In addition, most of the shows currently produced take advantage of a spatial sound system. But each theatre is different, either in its architecture (titled or not) or in its sound installation (5+1, 6+1, 7+1, others). Which files are supplied to the planetariums and how do they have to treat them to optimize their installation?

**David Beining, LodeStar Astronomy Center “Lessons in Collaborative Fulldome Training and Production”**
LodeStar has opened its dome to university students, visiting artists, researchers, and independent producers for more than three and a half years — including the world's only fulldome video festival, DomeFest. The collaborations have been both taxing and enthralling as a culture of fulldome production has developed in New Mexico. LodeStar will share some of the program designs, documents and tricks it has learned through the community-based efforts which have resulted in more than 150 fulldome producers and hours of content development. The presentation will describe practices such as dome orientations, production manuals, selection of supported producers and artists, file management, production reviews and public presentation of finished works. These practices have defined something of a standard — though not curbing — technique for LodeStar-based productions.

**Ryan Wyatt, American Museum of Natural History “Institutional Imperatives”**
Standards are the sort of dotted-i’s-and-crossed-t’s topic that cause planetarians to slumber, but our institutions have a vested interest in addressing standards issues explicitly and promptly. With media remaining costly to produce, distribution and collaboration must occur as painlessly and efficiently as possible: the definition of standards or “best practices” can significantly aid in this process. Furthermore, astronomical imagery taxes the display capabilities of many systems, which underscores the need more objective means of describing the quality of reproduction between systems. In the midst of these challenges, we lack even a basic vocabulary for describing many of the issues we need to address. In short, planetarians find themselves at the head of an emerging technology that combines significant advances in various arenas; we must navigate the headwaters cautiously but bravely, mapping out a route that enables increased institutional cooperation without curtailing future development.

Nearly all successful technology-based business areas thrive on technical exchange, recognition of excellence, and the establishment of industry standards. The fulldome industry has yet to institute such practices under a formal banner. The case is made for unity within the fulldome industry, including an annual summit that can act as a focal point for fulldome vendors, users and artisans
Charlie Morrow;
CMA studios create and master 3D works. Lake Technology spatializers. MAX/MSP and SPAT & ProTools and Logic.
Unlike surround and quadraphonic formats, 3D is not just in the ear level listening plane often with frontal experience on screen or stage. Many 5.1 surround mixes: “the best seat in the house.”
= up/down z axis, dramatic possibilities, no fixed front and back.
= is to surround ambiances as swimming is to a shower.

Leslie Gaston;

Methods for Sharing Stereo and Multichannel Recordings among Planetariums
Leslie Gaston1, Peter Dougall2, and Erick D. Thompson3
1 University of Colorado Denver, Denver, Colorado, 80217, USA
ACOUSTICS

2.1. Planetariums in General

The domed surface of the planetarium and corresponding loudspeaker placement present many challenges. Although loudspeaker correction would be highly recommended, in fact less than half of the planetariums surveyed (47%) use any type of equalization or delay to compensate for room anomalies. Other factors include the surface of the dome onto which the visuals are projected (acoustically transparent, perforated aluminum in most cases) and behind which the speakers are situated; the seating in the theater; the arrangement of the loudspeakers, and the type of construction material surrounding the dome itself.

A study done at Brigham Young University’s Summerhays Planetarium concluded that BASWAphon acoustic material can help control unwanted reflections from a planetarium dome, and is also good for projecting images. In addition, they found that directional loudspeakers improve speech intelligibility by keeping sound out of the dome. [1] [1] Shepherd, Micah et al, “Acoustics of a Planetarium”, 150th meeting of the Acoustical Society of America, 2005.

Planetariums would find significant benefit in equalizing and correcting for phase problems for loudspeakers. Manually taking readings and correcting equalization and phase problems takes a significant amount of time and hardware. Therefore it would seem most feasible to install and use a hardware system that will correct for phase and equalization automatically. Standards for speaker placement might be advantageous as well. A standard similar to the ITU 5.1 specification should be implemented if content is to be shared among planetariums without remixing. Such a standard must also consider the different venue layouts. So far, the IPS (International Planetarium Society) has merely recommended that the voice track be kept separate from other channels in order to allow foreign language
substitutions. (An international standards discussion is slated to happen during the Chicago IPS convention in June, 2008).

In our survey, over 90% of respondents said they would want some sort of standardization for sharing content and for installations. There can be some experimentation in speaker placement so long as equalization and phase correction act as a starting point.

Another possible solution for mitigating the problem of loudspeaker variances from one facility to the next is to use a planetarium as a "mastering house." For example, facility #1 could have calibration "snapshot" of a facility #2 that was taken using hardware such as the Optimizer. Facility #1 would then re-record the content with the phase and equalization settings from Facility #2 applied to the tracks, and send the corrected files (or tape) back to the Facility #2 for presentation.

2.3. Loudspeaker Correction

Loudspeaker correction is necessary in order to address the characteristics of a room. Correction in the frequency and time domains is particularly effective in correcting room response and lowering reflections [7].


Loudspeakers interact with a room to influence our perception of perceived image position, sense of spaciousness, and timbre [8].


7. If you answered "yes" to #6, what kind of surround format(s) do you use?

5.1 73.6% 39

Would you advocate moving towards some type of standard or recommendation to facilitate:

Ease of Sharing 92

Yes 92.4% (85)

No 7.6% (7)

Audio Quality

Yes 91.1% (82)

No 8.9% (8) 90

RSA Cosmos;
We propose the following elements:

- 7+1 sound system with voice (OV): 8 PCM 48 KHz mono files
- 5+1 sound system with voice (OV): 6 PCM 48 KHz mono files
- 7+1 sound system without voice: 8 PCM 48 KHz mono files
- 5+1 sound system without voice: 6 PCM 48 KHz mono files
- Stereo voice (OV): 1 PCM 48 KHz stereo file

Paul Bourke

1. Codec choice. It seems many (perhaps most) planetariums are not using lossless encoding/playback in which case the pixels being sent to the projection hardware are at a lower fidelity than the original rendered material. Personally I've always been surprised that some/many systems even use mpg and variants .... surely with today's hardware we can move past such compromising technologies.

2. Projectors don't give a 1:1 representation of pixels on the projection surface, this is especially so for CRT technology but also true for digital projectors. There are all sorts of sources for this including use of analog signals, the reality of lens physics, focusing on a curved surface, etc.

3. Many multiprojector systems use digital warping to correct for the spherical geometry, this lowers the information content.....individual pixels get contributions from neighbours so are no longer independent.

4. Edge blending is rarely (if ever) perfect, the result is usually a blurring (often significant) of the image between the projection patches.

I'm sure it is easy to find examples of planetariums with significantly higher theoretical projected resolution but where content looks worse than planetariums with lower spec'ed projection hardware.

One should also note that just because raw pristine frames may have a certain pixel count, that certainly does not mean it is higher resolution (in the informational sense) than content with a lower pixel count. This is clearly the case for filmed material, but also for CG. The resolution as it relates to quality is dependent on things such as antialiasing settings, quality of the model geometry, texture resolution, and other factors related to rendering technique.

Techniques and Technologies
Paul Bourke
WASP University of Western Australia
“Generally” agreed standards, but between competitors!
- 30 fps becoming more common than the NTSC 29.97 fps.
• Frame resolution has been increasing from 2400, 3200, 3600, ... some sites now ask for 4096 pixels square = 16 MPixels. Square pixels, reflects the CG (instead of filmed) history of fulldome.

• Frames are usually created/archived in a lossless format, historically TGA. Better more powerful images formats are starting to be used, in particular, PNG and less commonly TIFF.

• Audio: generally surround 5.1, quite a bit of variation between installation capability ranging from simple stereo to 7.1.

• Fisheye orientation with “front” at the bottom of the image. This is a view of the image from within the dome rather then from above the dome.

• Not uncommon to place information within the unused portions of the circular fisheye frame. Eg: frame number, sequence name, author ... no standards.

• In reality, for an optimal result, one does need to know certain details of the final projection environment. During content creation it is critical have access to the final projection installation, certainly at the start of the process.

• Differences due to variations in projection systems:
  - Resolution capability of projection system.
  - Dome surface characteristics, reflectivity.
  - Colour space differences, gamma, white point, temperature ....
  - Full fisheye projection vs truncated fisheye.

• Differences arising from the building/dome:
  - Uni-directional vs onmi-direction seating.
  - Dome tilt angle: 0 degrees (planetarium), 30, 45, 90 degrees (upright dome).
  - Height of viewers below the spring line.
  - Degree of seat tilt.
  - Full hemispheres and partial, not all domes are full hemispheres. All the above generally determine the natural center of attention on the dome.

• Differences due to imperfections:
  - Degree of edge blending artifacts for multiple projector systems and where they occur on the image.
    - Variation in dome surface quality, for example with inflatable domes

Resolution: for content today it varies from 1024x1024 pixels (lower end single projector installations) to 4096x4096 pixels for the high end multiple projector systems.

• Interesting to consider that for a given image resolution the size of the dome does not change the perceived resolution. The angle a pixel subtends at the eye is the same irrespective of the dome radius.

• Difficult to compare resolution between some technologies, for example, current digital
projectors (if in focus) can result in individually resolved pixels on the dome, this is not necessarily the case for analog CRT systems. Also screen door effects on some projectors.

• Some knowledge of the dome resolution is relevant to content production as it determines the finest detail that can be represented

Cannot necessarily create high definition 4K fisheye images and expect to be able to downsample for a lower resolution installation. Especially true for high definition content converted to single projector systems, fine detail can be lost in the antialiasing that occurs in a downsampling process.

• The same applies to detail within 3D models, fine detail that can be resolved in a 4K render may not be resolved in a 1K render due to aliasing effects.

• Resolution on the dome does not necessarily have a 1:1 correspondence with the resolution of the source fisheye images, for example most system employ lossy compression codecs.

• Estimates vary but the human visual system can resolve down to around 3 arc minutes. Surface area of a hemisphere is 2 \pi r^2 so 3 arc minute resolution needs about 13 MPixels.

• Opinions vary regarding the importance of ultra high resolution compared to the story telling component/skill. At what stage does the resolution not become the determining factor to the experience?

Projection system contrast is typically measured as the luminance ratio between pure white and black. Very difficult to judge the importance given that the human visual system can adapt across a very wide range of brightnesses. Contrast ratios as quoted by projector manufacturers generally mean little when applied to fulldome projection.

• Note that our visual system is more sensitive to relative brightness differences rather than absolute brightness, as well as having a very non linear response. It is this characteristic that means that relatively low brightness projection systems can be used as long as black out lighting conditions are imposed.

• Dome reflectively. This is probably the most significant factor, cross reflections within a dome and seriously diminish the result (low contrast). A high gain white dome is NOT what you want, compared to desirable high gain flat screens.

• Very difficult to control from a producers point of view because accurate (desired) representation of colour requires a careful calibration of every part of the production process, from rendering, post processing, compositing, to projection.

• In many/most cases the characteristics of any two installations will be different. No real solution while there is no standardisation across installations.

• Note that high contrast projection systems assist in the apparent 3D effects mentioned earlier that can occur

in Colour space refers to the colours that can be represented given a particular projection environment/technology. This also applies to image generation and capture.

• Colour space (enclosed area) from CRT projectors is quite small.

• For DLP there is a tradeoff between colour primary and brightness, the larger the colour space the dimmer the projection. Manufacturers of commodity projectors at least aim for high brightness and therefore poorer colour space.
• The key advantage with laser projectors is the large colour space they can support.

• Accessible parameters: projection system gamma, white point, temperature. Without a fully calibrated production process gamma is the simplest parameter to control. Note also that some projection devices have gamma curves that deviate from a simple power curve, in order to make them more suited to other projection applications.

• Rough starting point is gamma of 2.2 (power law relating pixel values to luminance) and a white point of 6500 Kelvin.

• Bottom line: the technologies to fully utilise or match colours between devices are largely not understood by developers, they are inherently problematic, and the tools not in wide use. End result is most developers fly by the seat of their pants, optimise their content for the intended installation and hope it works OK in others or can be modified (image based) to do so.

• Interesting to consider rendering HDR as a way to maximise the chances of post processing

General categories:
- inflated, generally fabric.
- negative pressure, generally fabric.
- fixed, most common are planetarium domes.
- constructed from plane faces.
- upright solid domes, often simulators

Speed at which things move across the fisheye dome. Generally need to move objects much more slowly than traditional animation. Similarly it is important not to have sudden jarring start and stops in the animation.

• Camera motion needs to start/stop smoothly, similar to real life where everything has momentum. This is equally true for filmed footage where very careful attention needs to be paid to any camera movement.

• Text size and the amount of the dome a single piece of text occupies, difficult to read across a wide field of view. Generally should keep a text token within a narrow enough field of view that head panning isn’t required. Animated text (because it is generally across a larger distance than usual) tends to be more difficult to read in a dome environment. Another consideration related to text size is to ensure that text that is legible on a 4K fisheye is also legible on a 1K fisheye, assuming distribution to lower resolution domes is intended.

• As a general rule higher levels of spatial antialiasing (to overcome visible pixel borders across between high contrast transitions) are required for dome content. Objects typically occupy a larger field of view, pixels are larger, and there is curvature even in normally straight geometry.

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**National Science Foundation Study Grant Final Report Development, Testing and Implementation of Digital Imaging Techniques for Enhanced Learning Applications in HD, 3D and Dome Theater Immersive Environments**
William N. Lange, Evan Kovacs, Maryann Keith, Kathryn Rose
Introduction

Results from Early Testing
Preliminary test screenings in dome theaters quickly pointed out a number of expected and unexpected results. These can be broken down into two main categories:
1. Viewer issues due to viewing angles and screen geometry of the dome
2. Image fidelity issues relating to both image acquisition and dome physical characteristics

Viewing Angles and Geometries
There are many differences in viewing angles and geometries for domed theater venues due to the differences in overall size, i.e., diameter and tilt angles. The size of the dome, which can be anywhere from a few to 30 meters, greatly affects how the audience perceives the imagery being presented. Further complicating this issue is the tilt of the dome theater screen, which also varies from horizontal in panoramic display venues to vertical in planetarium venues.
Our testing has shown that imagery collected in full dome must be geometrically corrected to fit the various sizes of dome screens. The resultant fields of view change during this process and the effect can most noticeably be seen as the imagery appearing too close to, or too far from the observer.

Physical Characteristics of Dome Theaters that affect Image Fidelity
Picture Height
Current standard definition television systems use a picture height to viewing height ratio of about 7:1 for determining best viewing distance.
Current HDTV television systems use a picture height to viewing height ratio of about 3:1 for determining best viewing distance.
Dome theaters generate a picture height to viewing height ratio of about 1:1 for audience viewing distance.
Small portable dome theaters generate a picture height to viewing height ratio of about 0.5:1 for audience viewing distance.
These items demonstrate that higher quality imagery projection is required for small domes in order to maintain comparative image quality over larger dome venues. This, however, is rarely the case as most portable domes use lower quality projections systems and screens. In addition, the content is usually compressed higher than what is used in permanent theater venues. This is often overlooked by viewers due to the novelty of the dome environment and that the majority of content being displayed is coming from high-resolution sources, such as computer data visualizations. Live imagery will need to be 2-4 times the resolution of the larger dome theaters to maintain the same overall perceived resolution. This is currently not feasible which may result in a loss of image content
fidelity in small dome theaters. Small domes do, however, represent an ideal
demonstration and educational environment for data visualizations and similar visual
media.

Results, Findings and Recommendations

Post Processing
During the course of this study, we discovered that the file formats and compression
techniques used on various brands of image servers, especially in dome theater
applications, represented a direct affect on perceived image quality. A comparison of
widely used still image file formats used during slicing operations showed a wide range
of subjective image quality and fidelity issues. During this study we have moved towards
using the least destructive of the image file formats for processing, slicing and
distribution.

Post processing Pipeline Development
WHOI is working with Sky-Skan Inc to develop a more efficient and higher image
fidelity technique for the processing of images for Dome and 3D screen Venues.
An example of a post processing pipeline is as follows:
Acquisition at Full Bandwidth Lowest Compression Recording
  Preliminary Color Grading
  Sharpening
  Scaling
  Post Grading
  Projector Grading
  Sharpening
  Geometric Rectification
  Projector Geometry Correction
  Slicing @ RGB 12 bit Avoiding destructive image file formats

Future Areas for Study
  o Dome Rectification Study
    ▪ Translating to various dome sizes and tilts
    ▪ Develop universal optimum for non-vertical domes
    ▪ Develop vertical dome display venue
  o Image Processing and Pipeline Development
    ▪ Scaling and sharpening algorithms
    ▪ Grading

Presented at the IPS 2004 Fulldome Standards Summit, Valencia, Spain, 7/8 July 2004

Color Reproduction Complex

The color space is a theoretical model indicating all colors which can be projected by
a projection device. Currently, different types of projectors are used for digital image representation in planetariums. They include CRT, LCD, DLP or laser projectors. Currently, projectors are compared by their main performance features such as:

- maximum brightness
- maximum contrast, dark light
- resolution of image-providing element, the image source

However, as laser projectors are introduced, another parameter of major significance emerges:

- the presentable color space

A color transformation is necessary whenever the primary colors, for example, of a light source do not match those of the display device. In order to transmit identical color information, a given color position must be described by a different relationship of primary colors. This is accomplished by way of mathematical transformation. As an important prerequisite, no color must be changed by this procedure and calculation must be possible in real-time. Fast switching of color transformation proves very useful.

Contrast. There are a number of parameters with an influence on the final visual impression that a viewer will have of a given picture. Of major significance in this context is the inherent contrast and the dark light level of an image. The human eye perceives differences in brightness rather than brightness levels. Accordingly, absolute brightness is not of prime importance to the viewer. Hence, a strong image contrast is responsible for high color saturation. In other words: extraneous light in an image reduces the level of color saturation and results in an impaired color impression by the viewer. In addition, excessively strong contrast produces a quasi 3D-effect in many cases. Where there is a black background, the human eye will be unable to adapt so the image is “suspended” in the air.

Influence of Projection Optics
Another factor of importance for color impression and color resolution is the selected projection optics. The result decisively depends on how the information of an image source is projected onto a screen surface. On this transparency, you can see the image information as generated on the one hand, and the same image information as projected onto a screen surface by projection optics on the other hand. Projection optics of any kind implies some deterioration in image information and contrast. What finally matters to the viewer are the parameters of the image he or she perceives on the projection screen.

At the moment, there are no generally established methods for working with an extended color space.
Working With a Desaturated Space (gamut)

Transparency 14
A control monitor is used for development of image contents. No laser projector is required in this case. This version should be given preference where the laser projector is needed for demonstration so it is not always available for development work. For definition of colors, a standard (desaturated) color space (gamut) is selected in this case. Maximum color saturation on the monitor will correspond to maximum color saturation during subsequent reproduction by the laser projector. White will remain white and the relative saturation degree is also preserved. For representation with the laser projector, the internal color transformation function is turned off.

Working With Preexisting Image Contents

Transparency 15
a) Switching from sRGB to Laser Color Space
Where preexisting image contents are available, you are able to utilize an extended color space with color transformation turned off. This option can be selected for the majority of image contents on display in planetarium applications. The various image contents are perceived as more brilliant and more colorful by the viewer in this case. As the color space is subject to some spreading, there will be a shift in the resulting colors of your image contents. This has no adverse effect in most cases. There is, however, a restriction for human face colors or correct-color representations. For image contents of this type, color transformation must be turned on again to render them in their original colors. Color transformation may be turned on and off during a running planetarium session.

b) Increasing color saturation in laser projector operating software
Presented at the IPS 2004 Fulldome Standards Summit, Valencia, Spain, 7/8 July 2004
The operating software provides a controller tool to increase color saturation. This option allows you to prevent hue-shift effects. Whether it should be applied or not, depends on the particular image contents.

c) Mathematical algorithms for color spreading
This option is not yet commercially available, but in the process of development. Color spreading means that calculatory algorithms are specifically designed to achieve a targeted amount in color spread. This technique has a clear potential for increasing color saturation. With critical colors, there may be falsification effects.

the human eye’s perception can
be influenced by various technical parameters.
What ultimately matters for the viewer is not a single performance feature of the projector, but the effect which an image on a projection screen has on him or her. The human eye is no measuring device – it just perceives in its own way. The crucial point that makes a projection actually good is whether all projector settings match the eye’s perception.

NASA EXPLORER INSTITUTES’ FOCUS GROUP - FINAL REPORT
SEEING THE UNIVERSE

February 2-4, 2004

American Museum of Natural History, New York, NY

Organizing Committee:

• Laura Danly (AMNH)∗
• Ryan Wyatt (AMNH)
• Carter Emmart (AMNH)
• John Stoke (STScI)∗
• Steve Lee (DMNS)∗
• Frank Summers (STScI)
• Judy Koke (Univ. Colorado)

The vast quantity of high-quality space science data acquired by NASA’s missions and scientists is providing revolutionary new understandings of our Earth and sky. At the same time, advances in computational power allow us to depict current astronomical discoveries with unprecedented fidelity, providing audiences with an opportunity to experience the universe as never before. SEEING THE UNIVERSE brought together visualization providers, users, commercial vendors, and NASA scientists and mission personnel to identify the next steps in coordinating efforts to bring superior visual experiences to NASA’s audiences.

Most significant best practice: The team approach that combines scientists, artists, animators, programmers, and end users from the informal education community has lead to the most successful, high-quality visualizations.

Most significant lesson learned: Tremendous opportunities exist to expand the reach and power of NASA data visualization by organizing the community to assess and develop appropriate strategies for advancement; we can make a big difference with a few simple next steps.

Most significant accomplishment: The astronomy and space science visualization community has not met before on this scale. Our most significant accomplishment was the development of a true community identity with a commitment to working together to advance astronomy visualization for all audiences.

∗ will attend the NEI Planning and Evaluation Meeting, March 15-18, 2005
Most significant unanticipated outcome: All those involved in scientific visualization comprise a distinct community, apart from other scientific or informal education communities, with common goals and unique needs. NASA should establish an organized, coherent program across NASA to coordinate and support scientific visualization that serves the full range of NASA’s audiences and needs.

R.S.A. COSMOS
FULLDOME STANDARDS SUMMIT
IPS 2004

It is important to think about a standard taking into account all the market and not only the American market.
It is important that this standard does not exclude the future technical solutions. Indeed, a planetarium which has chosen a technology different from this standard must have access to the standard shows (unlike the old planetariums with the Levels standardization)
Manufacturers must adapt themselves to the market requirements and not the contrary.
Manufacturers must not impose their standards on the market but, on the contrary, the standard must adapt itself to the market.

What specifications of the projection system should be taken into account in order to create a standard exchange of AllSky video shows?
Fish-eye images have been already adopted as standard by the community, so it is important to define how to obtain them, their resolution as well as a working chain allowing the planetariums to use them.
The fish-eye images rendering method will have to meet the requirements of the planetarium producers according to their technical, temporal and financial means.

NTSC is used in North America (and in a part of South America) as well as in Japan.
PAL is used in the rest of the world (Europe, Australia…)
Historically, the choice of the image frequency is above all linked to the electrical network used: 50Hz in Europe : 25fps (or 50 for interlaced images) and 60Hz in the United States: 30 fps (or 60 for interlaced images).
Two parameters must be defined:
- Resolution
- Broadcasting frequency
Note about HDTV: resolution 1920*1080 (2073600 pixels): ratio of 16/9 not very adapted to our projection configuration 5/4 or 4/3. Computer resolutions 1024*768, 1280*1024, 1600*1200 (1920000 pixels) are adapted to our requirements and have only 8% fewer pixels.

2.3.1 Projection frequency
Projection frequencies (scanning frequency of the projector) are generally 60Hz or 75Hz.
As we will see in the next point, the two video frequencies used (images frequency) are 25fps or 30fps.
The frequency of 75Hz is adapted to 25fps video (75 = 3 * 25)
The frequency of 60Hz is adapted to 30fps video (60 = 2 * 30)
On a 75Hz projection, 30fps video is acceptable (75 = 2 + 1/2 * 30)
The images projection cycle is:
(3-2)-(3-2)-(3-2)- etc. so the jerky appearance is not very evident.
On a 60Hz projection, 25fps video is not acceptable (60 = 2 + 1/ 2.5 * 25)
(3-2-3-2-2)-(3-2-3-2-2) etc. a jerky appearance is very evident.

We remind you that the frequency used for movies is 24fps. It is a very good quality which has been used for a long time !!

3.2.1.1 Calculation of the number of effective pixels on the dome
Example of a 5+1 planetarium which can play back on each channel a resolution of 1600*1200.
1600 * 1200 * 6 = 11 520 000 pixels projected.
You have to subtract the pixels duplicated by the soft-edge zones (we take an average of 20% of soft-edge, obviously this value changes according to the site and the adjustment of the projectors).
11 520 000 * (100% - 20 %) = 9 216 000 effective pixels on the dome.

3.2.1.2 Calculation of the number of effective pixels of the Fish-Eye image
Presented at the IPS 2004 Fulldome Standards Summit, Valencia, Spain, 7/8 July 2004
A Fish-Eye image is a circle in a rectangular composition. The image’s diameter is the smallest side of the rectangle (of the side if it is a square).
Example of a square image of 2200*2200 in which there will be a Fish-Eye.
The number of effective pixels of the Fish-Eye image is:
PI * (2200 / 2)^2 = 3 801 336 effective pixels.

3.2.1.3 Comparison between the number of pixels available on the dome and the number of effective pixels of the Fish-Eye image
Ratio = ( Number of effective pixels of the Fish-Eye image) / (Number of effective pixels on the dome) %
In the previous example, the ratio is 41% (<100%). The number of pixels of the Fish-Eye image is 2.4 times more little than the effective resolution of the dome and so, it is not enough to exploit the capacity of the projection system.
The Fish-Eye image must always have a resolution 10% better than the dome and so, the ration must always be superior to 110%.

3.2.1.4 Conclusion
Below is a table concerning the Fish-Eye image which must be used according to the number of projectors and the video resolution used. We used the previous method and a 20% softedge

<table>
<thead>
<tr>
<th>Video channel resolution</th>
<th>Number of channels Minimum resolution of the Fish-Eye Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>720 * 576 5 + 1</td>
<td>1700*1700 114 %</td>
</tr>
<tr>
<td>1024 * 768 5 + 1</td>
<td>2300*2300 110 %</td>
</tr>
<tr>
<td>1280 * 1024 5 + 1</td>
<td>3000*3000 112 %</td>
</tr>
<tr>
<td>1600 * 1200 5 + 1</td>
<td>3600*3600 110 %</td>
</tr>
</tbody>
</table>
Fish-Eye images splitting
To convert from a Fish-Eye view to several views which can be played back on multiple projectors, you have to split the Fish-Eye. The software O.R.I.O.N™ can

We prefer a 7+1 configuration because the spatial sound is better especially at the zenith of the planetarium.
On the other hand, the classical 5+1 configurations offer different qualities of loudspeakers:
- Centre forward (Voice)
- Right forward, left forward (Music + Effects)
- Right Back, left back (Effects)
We propose to use the same loudspeakers whatever their position in order to have the same sound quality everywhere in the dome. The spatial sound effect is more important than in a cinema because the projected image is 360° azimuth and 180° elevation.

We propose to supply a
Presented at the IPS 2004 Fulldome Standards Summit, Valencia, Spain, 7/8 July 2004 soundtrack with a show as uncompressed PCM files with a 48 KHz frequency. The sound file size is very small respect to the images (around 10Mb per minute).

For sound reproduction, it is best to have one discrete file per loudspeaker. Nevertheless it is true that to have the best quality, performing the mix in the theatre on the final configuration is essential.
An other element to consider for the show exchange is the translation of the show, which is rarely done by the company who supplies the show (planetarium or specialised company). The “Voice” track must be separated to be changed.
In any case, it is more practical to receive individual channel files for processing rather than only one AC3 file which will be totally closed and impossible to modify.
We propose the following elements:
- 7+1 sound system with voice (OV): 8 PCM 48 KHz mono files
- 5+1 sound system with voice (OV): 6 PCM 48 KHz mono files
- 7+1 sound system without voice: 8 PCM 48 KHz mono files
- 5+1 sound system without voice: 6 PCM 48 KHz mono files
- Stereo voice (OV): 1 PCM 48 KHz stereo file

Telus World of Science Edmonton TWoSE
Full-Dome 3D Digital Science Visualization
George Smith, CEO of TWoSE
Logistics, housekeeping, disclaimers & facilitation - Ian McLennan

SYMPOSIUM IN FOUR QUARTERS, 8-10 May 2007
matching raw content with sophisticated presentation standards

- work on documenting sources (public domain and otherwise)
A Software Infrastructure for Facilitating Scientific Discovery and Knowledge Transfer within the AlloSphere

The Allosphere represents the next generation of collaborative immersive environments that support the development of arbitrary scientific visualizations using the same software base. To this end, we propose to use an OpenGL “lift-off” approach that allows codes written for standard OpenGL to be automatically enabled in the Allosphere.

To begin with, by targeting OpenGL specifically, we maximize the potential for other groups to leverage our software base which we plan to make freely available. In particular, public planetaria constitute a particularly unusual user community that this work will target. The Allosphere shares much of its technology with digital dome planetaria, of which there are a few hundred in the US today. These facilities are dedicated to science education and outreach on a large scale, making the potential impact of our work quite broad.

Collaborative and interactive visualization sessions commonly take place in special purpose visualization environments such as virtual reality CAVEs [8, 9, 39] and other multi-projector reality centers [15, 26], or in front of stereoscopic display walls [32] or immersive workbenches [28, 10].

With 14 projectors in the current installation (more are planned), the total number of pixels it can represent is approximately 20 million, which represents a 3 to 4-fold increase over high-resolution non-tiled CAVEs. For comparison, eye-limited resolution is approximately 150 million pixels.

We propose to build an integrated software infrastructure to bring data visualizations from the scientists’ desktop computers to the Allosphere without requiring the researchers to change their normal work practices.

Automating the conversion of arbitrary desktop OpenGL visualizations into 3D surround-view presentations in the Allosphere or full-dome planetaria. We go beyond the current abilities of, e.g., the Chromium [25] library by enabling the conversion of a single 2D desktop OpenGL viewport to the immersive, stereoscopic, surround view, and correctly spherically distorted presentation of the 3D content, which may also make use of the latest GPU shading language capabilities.

• providing an innovative approach in utilizing spatial sound cues in the visualizations based on specific colors that the scientist allocates to specific geometric elements or simulation events
• an easy-to-use API and porting path to make use of tracking and multi-modal support in our immersive space, and
• a series of performance optimizations for our approach compared to existing state-of-the-art solutions.


Lantz

Presented at the IPS 2004 Fulldome Standards Summit, Valencia, Spain, 7 July 2004

1

**Fulldome Display Specifications: A Proposal**

Ed Lantz
Visual Bandwidth, Inc.

Abstract. General standards are proposed for specifying fulldome displays. Proposed specifications include brightness, brightness uniformity, color uniformity, contrast, resolution and update rate. A methodology for measuring edge-blend uniformity is proposed, and suggestions are made for approaching more difficult parameters such as color gamut.

---

**Display Parameter Measurement Unit**

**IPS Light Output** Full-white (over entire dome) luminous flux actually delivered to dome surface, accounting for projector masking, overlaps, blending, and color matching. Uses ANSI lumens technique.
lumens (l)

**IPS Peak Light Output** Same as above, except the measurement is made with a small area of white rather than full-white which can drive CRT projectors into current limiting.
lumens (l)

**IPS Brightness (30/50 method)** Average full-white brightness produced on 30-foot diameter dome screen with 50% reflectivity.
foot lamberts
Brightness
Uniformity
Peak-to-peak variation in brightness across the entire display, with respect to the average brightness. Specification must hold for all three primary colors in addition to white.
percent (%)
IPS Blend
Uniformity
Worst-case peak-to-peak variation of brightness measured at three points along a line perpendicularly intersecting the blend region (points measured at center of and on either side of blend region). Specification must hold for all three primary colors in addition to white.
percent (%)
IPS Resolution Minimum number of pixels projected per degree of arc on the spherical surface, assuming a nominal angular projection (180-degree hemispheric projection for fulldome systems). For non-digital displays a 50% MTF criterion is used.
pixels/degree
IPS Contrast Instantaneous contrast ratio of typical system (not individual projectors) using IPS test pattern.
N:1 (ratio)
IPS Sequential Contrast
Frame-sequential (full white/full black) contrast ratio of typical system (not individual projectors) using IPS test pattern.
N:1 (ratio)
Color Gamut CIE 1931 x, y values numeric x,y
Frame Rate Maximum, minimum and/or typical number of frames displayed per second, and whether the frame rate is progressive or interlaced.
Frames/second
Gamma (Your specification here)

I suggest using a 30/50 method where we assume a nominal 30’ diameter dome (units of feet to match the foot-lambert units) with a 0.5 reflectance (50% reflectivity).

Display Brightness (fL) = Screen Reflectance * Light Output (lumens)/Screen Area (sq. ft.)
In the case of light output or brightness, the ANSI technique of using a full-white field is employed.
**Brightness Uniformity.** Brightness uniformity refers to the peak-to-peak range of luminance values across the entire display surface, expressed as a percentage of the average brightness. Peak-to-peak brightness Bpp is found by:

\[ Bpp \% = \frac{(B_{\text{max}} - B_{\text{min}})}{B_{\text{avg}}} \times 100 \]

Where Bmax is the highest brightness measured in the set, Bmin is the lowest measured value, and Bavg is the average of all measurements. In theory this would include local luminance variations within blend regions as well as projector-to-projector variations. It is conceptually and empirically easier, however, to break these measurements into two separate categories – Brightness Uniformity and Blend Uniformity. Single-projector systems are exempt from the latter specification.

Flexibility is called for in brightness uniformity measurements. A rigorous method would be to make spot photometer measurements at fixed, equally spaced azimuth and elevation coordinates over the entire display. Such an approach would be overly burdensome, however, requiring perhaps hundreds of points to achieve an accurate measurement. Certain factors often dictate a specific set of measurement points. For instance, in a multi-projector system we might measure brightness at the center and four corners of each individual projector frame (avoiding the blend regions themselves). For a single-projector system, measurements might be made in four quadrants at a lower and higher elevation. Since it is intended to be a worst-case specification, then wherever the measurements are conducted the specification should still hold true.

**Blend Uniformity.** In edge-blended systems it is useful to have a measure of how seamlessly the projectors are blended. This may be accomplished by taking three measurements along a line that cuts through a blend region perpendicularly. One measurement (B2) is made at the center of the blend. The other two measurements (B1, B3) are made on either side of the blend. Blend brightness uniformity is therefore the peak-to-peak percent luminance variation through this region, given by:

\[ Bpp = \frac{(B_{\text{max}} - B_{\text{min}})}{B_{\text{avg}}} \]

Blend uniformity of approximately 5% or better typically results in a near-seamless blend, but this figure also depends on the angular width of the blend, which should be specified for completeness.

**Color Gamut.** Color gamut is a function of the color values used in the red, blue, and green primaries within the projector optics. The most commonly used color space for specifying gamut is the 1931 CIE Chromaticity diagram.
**Color Uniformity.** Perhaps the most difficult parameter to measure and specify is color uniformity. Again, the spatial parameter is crucial, with a given difference in color across a small region of the dome being more perceptible than the same difference spread over a larger area.

**IPS Resolution.** It is proposed that display resolution be expressed in resolvable pixels per angular degree (measured with respect to spherical dome coordinates). This measurement is easily understood and is especially compatible with newer digital projector technologies where pixels are nearly always individually resolvable. In the case of non-fixed panel displays such as CRT projectors, resolution would be the number of addressed pixels per degree provided that a 50% MTF (Modulation Transfer Function) is achievable at this pixel density. That is, when successive pixels alternate between white and black, the contrast ratio between the two shall be at least 50% at the highest pixel resolution.

50% MTF Requirement for Defining CRT Resolution

**IPS Contrast Ratio.** Projector contrast ratio is commonly measured using a 16x16 checkerboard pattern according to the American National Standards Institute (ANSI) standard. This method must be modified somewhat for the dome screen, resulting in a unique IPS contrast ratio specification. In a traditional neutral-density dome screen environment, the cross-dome scatter typically reduces the contrast ratio to 10:1 or less when used with a fulldome checkerboard pattern – a figure that varies from theater-to-theater depending on dome reflectivity, dome geometry, and theater finishes.

To achieve a theater-independent measure of contrast I recommend the adoption of a standard test pattern consisting of a white circle against a full black background with a small black cutout area within the circle.

**Frame Rate.** Finally, frame rate is of interest when comparing systems. This parameter is typically fixed, although some systems do allow a variable update rate. Frame rate is expressed in frames or fields per second, and is designated as either progressive scan (p) or interlaced scan (i).

**References**


IPS Contrast Ratio Test Pattern

Presented at the IPS 2004 Fulldome Standards Summit, Valencia, Spain, 7 July 2004

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**Fulldome Unity: The Need for Technical Exchange and Fulldome Standards**

Ed Lantz
Visual Bandwidth, Inc.

Nearly all successful technology-based business areas thrive on technical exchange,
recognition of excellence, and the establishment of industry standards. The fulldome industry has yet to institute such practices under a formal banner. The case is made for unity within the fulldome industry, including an annual summit that can act as a focal point for fulldome vendors, users and artisans.

For the record, I conceived this summit while working with Tom Lucas of Lucas Productions and the Denver Museum of Nature & Science on a proposal to the US National Science Foundation (NSF) for a fulldome planetarium show on black holes. Tom approached Spitz, my employer at the time, for help with distributing this original production. I explained that there weren’t any formal standards for show distribution, then asked if NSF might be interested in funding an effort to create some industry standards. Ryan Wyatt, another proponent of fulldome standards, agreed to join the effort as Co-Chair. The proposal team approved our summit sub-award to Spitz, who agreed to provide in-kind labor to manage the event. After the customary rounds of delays, our proposal was awarded by NSF early this year. Thanks to IPS President John Elvert and conference host Jose Guirado, the first Fulldome Summit was invited in as a special session of IPS.

What I would leave with you is this thought: it is better to grow together than to struggle alone. By joining forces professionally in an open exchange of ideas, by recognizing excellence and innovation, and by establishing new standards and practices, we improve our industry and better fulfill our missions.

there are certain problems that lend themselves to the synergetic mind that arise when a group of industry leaders gather and share their dreams, frustrations and successes. Focused paper sessions, panels and networking opportunities build such synergy, and also provide excellent educational opportunities for newcomers.

Acknowledgements. I would like to thank all who supported this effort, including Tom Lucas, the Denver Museum of Nature & Science, Spitz, Inc., and Spitz’s Creative Media Director Mike Bruno. Thanks to Co-Chair Ryan Wyatt who kept the momentum going while I was in career transition, and to his institution, the American Museum of Natural History for offering his time to our effort. Thanks to the Session Chairs Steve Savage, Kevin Scott, and Brad Thompson, and all the presenters who are providing the real substance of this Summit. Last but not least, thanks to the United States National Science Foundation for providing the funds that made this event possible.

HOWE,

A proposal for Dome Standards
Spatial resolution, luminance and system contrast
Author – Martin Howe, SEOS ltd
Date 1st July 2004

Spatial Resolution
Spatial resolution is the total quantity of pixels displayed at any point of time.
Spatial resolution can be described in many ways from the total number of pixels available from the media storage and delivery system, or the total number of pixels available at the projection system, or more importantly, the pixel density across the screen surface or the final resolution perceived by the viewer.

Of course, the perception of resolution depends upon three factors; the total number of visible pixels, the total area over which those pixels are displayed and the distance from the viewer to the screen.

In a (true) hemispheric visualization system, the total screen area is defined by the diameter of the Dome screen. By using a common view point, dome centre, the perceived spatial resolution of the Visualisation system can be defined simply by calculating the subtended angle to the eye at dome centre by two adjacent pixels on the screen surface.

Typically the human eye can perceive a spatial resolution between two adjacent pixels of 3 arc minutes (3 x 1/60th of a degree). Higher resolution is perceivable but typically only if there is a visible reference point available (i.e. comparing 3 arc minutes with 1 arc minute on screen). To distribute equally spaced pixels across a hemisphere at 3 arc minutes would require a total spatial resolution of around 10 million pixels.

**Luminance**
Luminance is a measure of the amount of light reflected from a surface over a given area. Expressed either in foot lamberts (ft-L, imperial) or candela per meter square (cd/m², metric). The luminance of a Visualization system determines the maximum brightness of the white point of an image.

this measurement is a useful comparison between hemispheric visualization systems using different projection technologies, dome sizes and screen gain and normalises these widely varying factors into a simple metric.

For comparison, typical luminance for a multimedia Dome can range between 0.2 to 1.5 ft-L.
A 20 metre diameter dome may need in excess of 40,000 lumens to produce
system luminance of 1 ft-L with sufficient system contrast. For reference 1 x ft-L = 3.43 cd/m².

**Contrast**

Probably one of the most important measures of a hemispheric multimedia visualization system is contrast, or more importantly, system contrast. Contrast is simply a measure of the difference in luminance of black and white, expressed as a ratio. However there are so many factors that determine the level of black and there are inherent system wide factors which are specific to spherical screens which affect contrast, that make it critical to express system contrast in a common way.

Interestingly, it follows that because cross-reflectance affects system CR then so does content. In other words, if a few star points are displayed, then cross reflectance is low and CR is higher; however if a large planet occupies half the screen area, then system contrast will be reduced. This system contrast ratio provides the range from black to white within which the content will be displayed.

**Summary**

Industry standard metrics that relate spatial resolution, luminance and contrast for the complete visualization system, independent of dome size or technology employed, would allow sensible performance comparisons to be made between different systems for the purposes of evaluation. Content could be configured according to these specifications and expectations could be set on how the content quality will be perceived by the audience.

Presented at the IPS 2004 Fulldome Standards Summit, Valencia, Spain, 7/8 July 2004

**Four Issues to Consider When Producing Fulldome Content for Wide Distribution.**

Brad Thompson, Spitz Creative Media

1. establish action and text safe areas for fulldome production
2. investigate how to deal with differently tilted domes
3. investigate how to deal with gamma issues
4. address what happens to stars when transferring content to systems with different resolution requirements.

**Nominal Camera Tilt**

**Action and Text Safe Areas**

**Gamma**

**Star decimation**

Preliminary results suggest that a star size of 4.0 pixels is capable of holding up well at both
3600x3600 and when rescaling to 1024x1024 for sequences where the stars serve as a backdrop for other imagery (planets, nebulae, etc.)

**Audio Format.** To accommodate for variations in sound systems in different venues, the original digital "stem" tracks and project files must be available for re-mixing or encoding for individual venues. A "generic" 5.1 mix is derived from these files as well as a number of odd formats such as 16.1. It is preferable to re-mix the sound in each venue when possible utilizing a portable editing system.

It is recommended that program soundtracks should be made available in (minimally) stereo and/or 5.1 surround formats. Audio shall be formatted as 16-bit, 48kHz .wav files.

Two versions of each soundtrack should be prepared: one that is timed for synchronization with 29.97 video and another that is timed for systems that use 30fps for video playback. Audio shall be provided as discrete mono channels, so that the show distributor may properly format/encode the soundtrack for the requirements of the specific playback system. The following naming convention shall be used:

**5.1 Format Soundtrack**

<table>
<thead>
<tr>
<th>USE</th>
<th>FILENAME</th>
<th>CHANNEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>required</td>
<td>filename_LR.wav</td>
<td>Rear Left</td>
</tr>
<tr>
<td>required</td>
<td>filename_FR.wav</td>
<td>Front Right</td>
</tr>
<tr>
<td>required</td>
<td>filename_L.wav</td>
<td>Rear Right</td>
</tr>
<tr>
<td>required</td>
<td>filename_Center.wav</td>
<td>Center</td>
</tr>
<tr>
<td>required</td>
<td>filename_LFE.wav</td>
<td>Low frequency signal (Sub-bass)</td>
</tr>
</tbody>
</table>

**Stereo Soundtrack**

<table>
<thead>
<tr>
<th>USE</th>
<th>FILENAME</th>
<th>CHANNEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>required</td>
<td>filename_FL.wav</td>
<td>Front Left</td>
</tr>
<tr>
<td>required</td>
<td>filename_FR.wav</td>
<td>Front Right</td>
</tr>
</tbody>
</table>

**Show Distribution Medium.** Dome master video frames and audio content should be delivered to Spitz on external PC-formatted (NTFS file system) 6-pin, Firewire drives. Video should be organized into folders according to frame numbers, typically with a maximum of 10,000 frames per folder. Audio should be organized into a 29.97fps folder and a 30fps folder, with sub-folders for stereo and 5.1 surround mixes.
• Potential or proposed fulldome industry standards
• Industry guidelines or “best practices”
• Standard nomenclature or terminology
• Standardized test frames or sequences
• New technologies that will affect standards efforts
• Methods to facilitate cross-platform show distribution
• Areas benefiting from greater vendor cooperation
• IPS support for standards and technological exchange
• Philosophical discussion of standards issues