Spherical Mirror Projection for Large domes

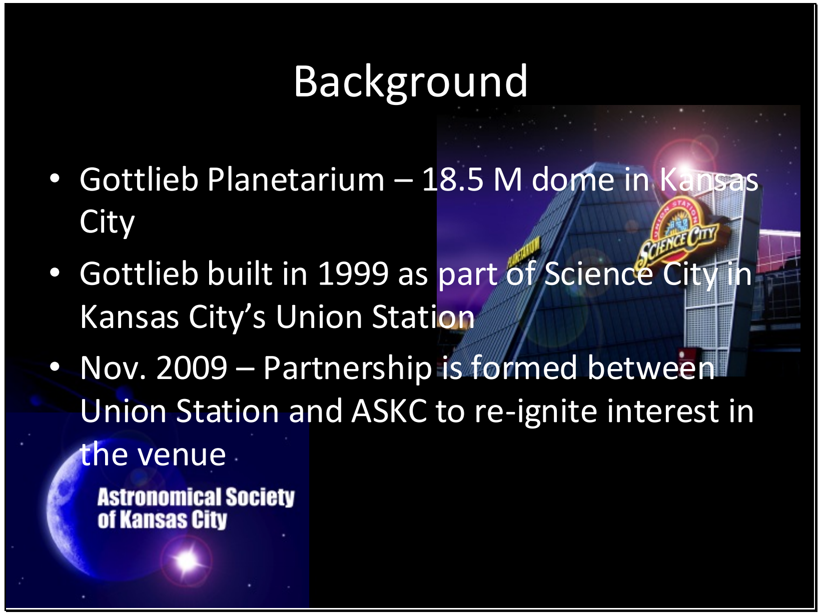
New ideas for maximizing brightness, resolution, and contrast for spherical mirror projection.

Presented by Bentley Ousley

Additional images:
Loch Ness Productions
Jack Dunn
Paul Bourke

Thank you for allowing me the opportunity to present at this conference. My name is Bentley Ousley. I’m a member of the Astronomical Society of Kansas City and a volunteer for the Arvin Gottlieb Planetarium in Kansas City.

I was involved in helping to design and build a new full dome projection system for the Gottlieb Planetarium and wanted to offer our experiences to those who are interested.



Background

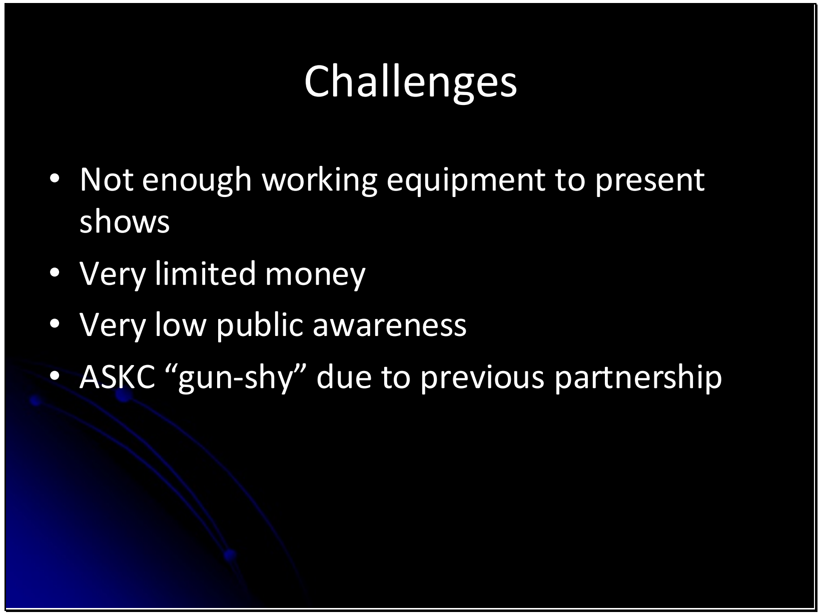
- Gottlieb Planetarium – 18.5 M dome in Kansas City
- Gottlieb built in 1999 as part of Science City in Kansas City’s Union Station
- Nov. 2009 – Partnership is formed between Union Station and ASKC to re-ignite interest in the venue

Astronomical Society of Kansas City

Gottlieb Planetarium was built in 1999 as part of a restoration project for Kansas City's Union Station. It houses an 18.5 Meter dome and is one of the attractions in Science City.

In November 2009 I attended a meeting that lead to a partnership being formed between the Astronomical Society of Kansas City and Union Station.

The purpose of the new partnership was to increase ASKC's involvement in raising awareness of the planetarium and develop ideas to re-engineer or replace the mostly non-functional or outdated projection equipment with a system that could re-ignite interest in the venue.



Challenges

- Not enough working equipment to present shows
- Very limited money
- Very low public awareness
- ASKC “gun-shy” due to previous partnership

At the beginning of the partnership we had several challenges to address.

- Not much was working in the planetarium, in fact there wasn’t enough working equipment to present shows.
- Union Station had been operating in the red for several years and internal money was extremely difficult to get.
- The Kansas City public was pretty much oblivious to the existence of the venue.
- ASKC members had previously been involved in a partnership that ended in a way that many in the club found grounds for being suspicious of any new agreement.

New projection system requirements

- A stable, reliable platform that would function day-to-day with few problems.
- Bright enough images, acceptable resolution, and good contrast on an 18.5 M dome.
- Compatibility with industry standard content
- A reasonable looking night-sky for star tours.
- Allows development of in-house content.
- Must cost less than $35,000

We determined that a new projection system was needed. We put together a list of minimum “must-haves” and set about researching what we might be able to do to satisfy these requirements.
Here is what was required:

- A stable, reliable platform that would function day-to-day with few problems.
- A system with bright enough images, acceptable resolution, and good contrast on an 18.5 M dome.
- Compatibility with industry standard content
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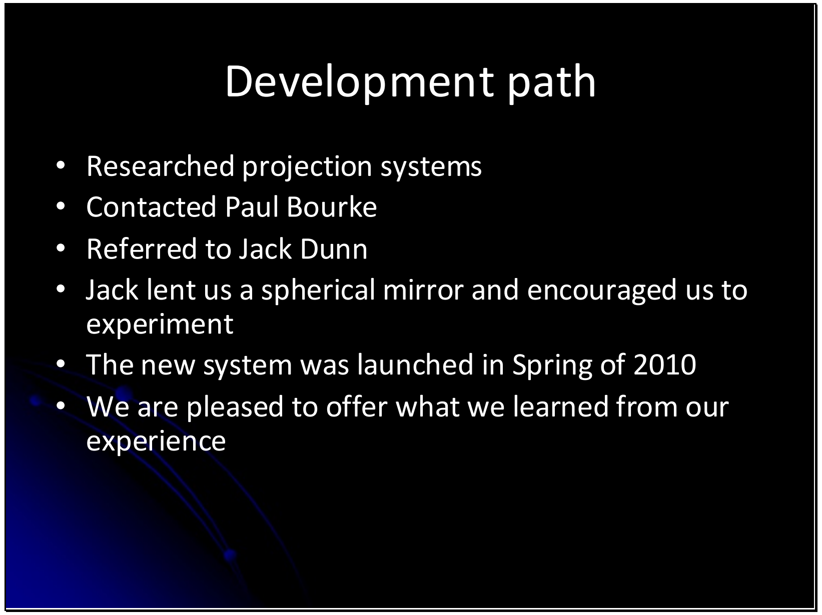


Development path

- Researched projection systems
- Contacted Paul Bourke
- Referred to Jack Dunn
- Jack lent us a spherical mirror and encouraged us to experiment
- The new system was launched in Spring of 2010
- We are pleased to offer what we learned from our experience

In our research for possible projection systems, we became intrigued with the idea of Digital Spherical Mirror Projection as developed by Mr. Paul Bourke at the University of Western Australia in 2003. There was a wealth of information online and Paul courteously agreed to advise us on our project.

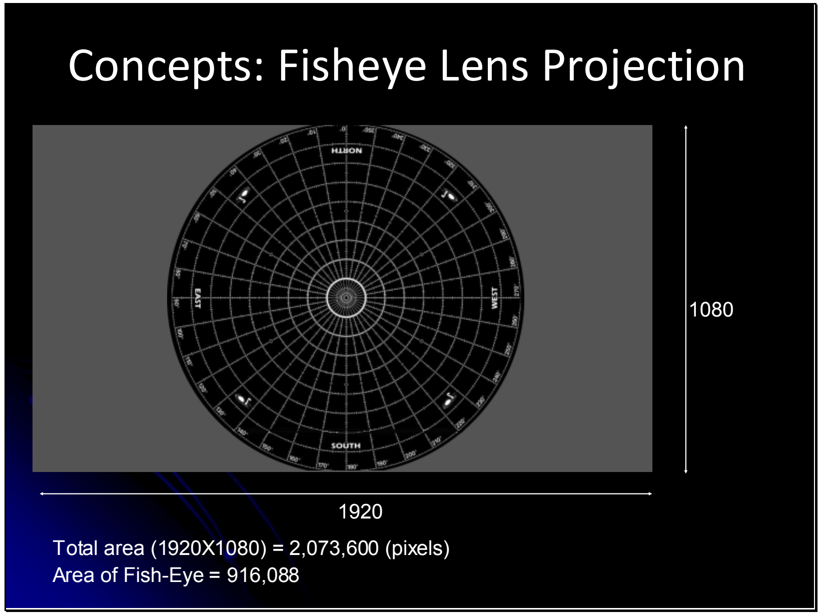
Paul recommended we contact Jack Dunn, longtime Director of the Meuller Planetarium at the University of Nebraska at Lincoln.

Mr. Dunn had helped set-up several new spherical mirror projection systems and was a wealth of information on the topic. No planetarium as large as Gottlieb had successfully implemented this type of projection system in the past. In fact, we were advised by some vendors that this type of system was impractical in a venue as large as Gottlieb.

[Comment by Paul Bourke: Actually the Bangalore planetarium implemented spherical mirror projection in 2005, it is a 20m dome. And the Gravitational Discovery Centre in Western Australia installed a spherical mirror system in 2010, it is also very close to 20m diameter].

Mr. Dunn lent us a spherical mirror and encouraged us to experiment. His advice has been invaluable and we are greatly indebted to him for his help. After some experimentation, we made the determination that we could meet the minimum requirements we had outlined previously. In the implementation of this system, we discovered some ideas that made the system perform considerably better than we had expected.

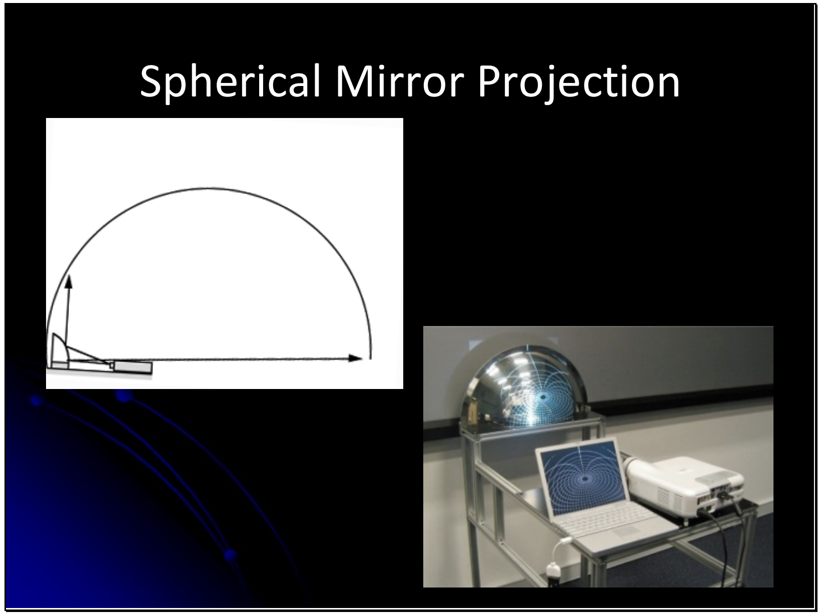
Even though many of these concepts were developed to improve the performance of a large dome system. It is our hope that you find some of these ideas helpful.



Concepts: Fisheye Lens Projection

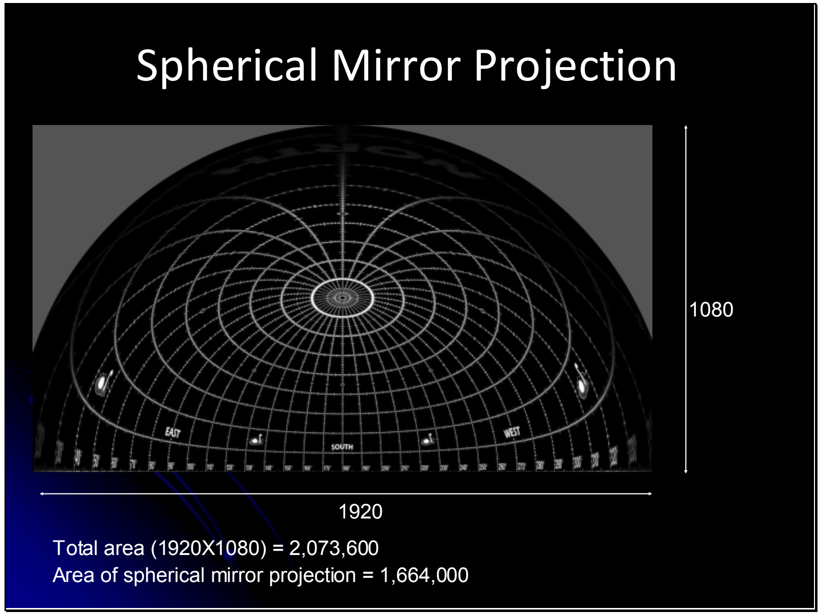
Total area (1920X1080) = 2,073,600 (pixels)
Area of Fish-Eye = 916,088

Concepts:
Bear with me while I cover some background information.
Pictured is a radial grid representing the full dome projection area for a hemispheric 180x360 degree dome. The center of the grid represents the zenith of the dome. The circle inscribing the outside edge is the area of the dome nearest the cove. The bottom is the front of the dome. The top is the rear of the dome. Single Fisheye Lens fulldome projection involves sending a Fish-Eye compensated image (such as this) through a digital projector fitted with a Fish-Eye lens placed in the center of the theatre, aimed directly overhead.
The grey area represents the area of a standard 1920 X 1080 pixel HD projection. As you can see by this image, the number of pixels that are actually used to project the fisheye image account for less than half the total number of pixels available in the HD projection.



Spherical Mirror Projection

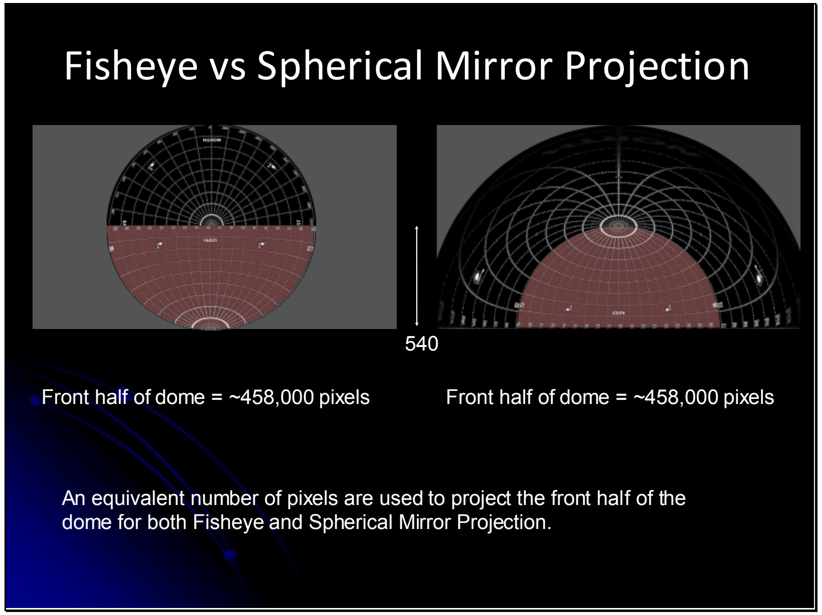
Spherical Mirror Projection is typically done by a projecting a specially warped image onto a first-surface Mirror in the form of a section of a sphere. The mirror and projector are typically located at the rear of the theatre near the cove at the bottom edge of the dome.



Spherical Mirror Projection

Total area (1920X1080) = 2,073,600
Area of spherical mirror projection = 1,664,000

The particular type of image warping that is used in spherical mirror projection allows more pixels to be projected on the dome.
At first glance, this looks ideal, more pixels on the dome mean brighter images and more resolution, right?



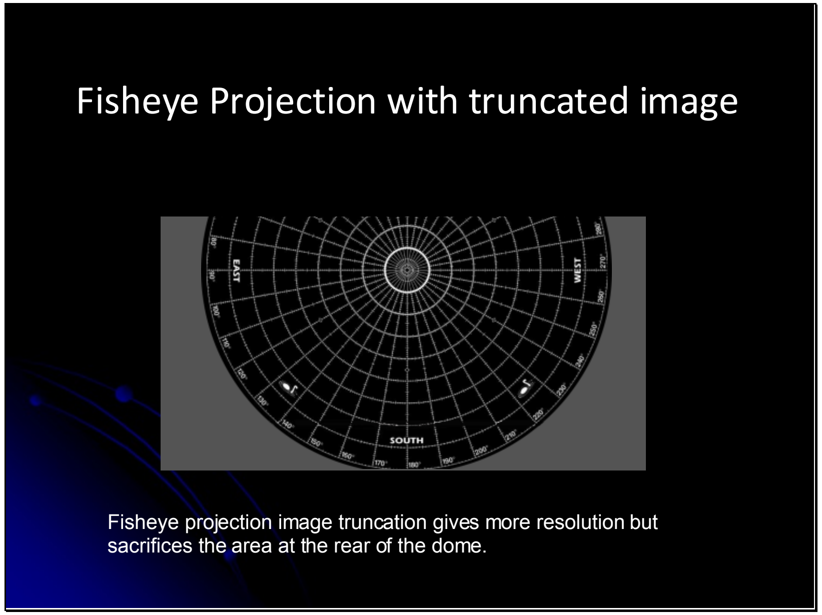
Fisheye vs Spherical Mirror Projection

Front half of dome = ~458,000 pixels

Front half of dome = ~458,000 pixels

An equivalent number of pixels are used to project the front half of the dome for both Fisheye and Spherical Mirror Projection.

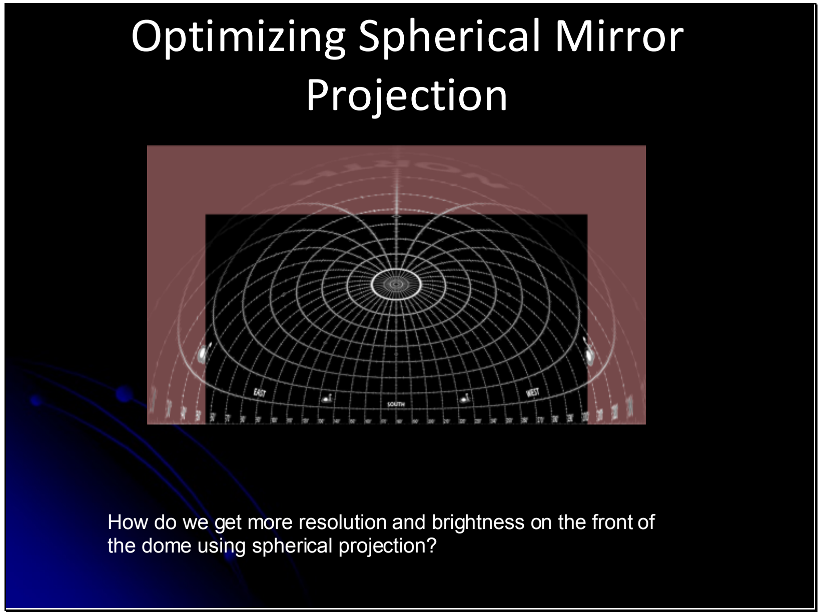
The areas shown in red are used to project the front half of the dome. Notice that about the same number of pixels are used to project the front half of the dome for both Spherical Mirror and Fisheye setups.
Although more pixels are brought to bear with spherical mirror projection, the pixels that are gained by warping are projected at the rear of the dome. As you can see, the situation is not ideal - the areas of greatest resolution are projected behind the audience.
Another issue - the rear of the dome is where the warping artifacts of spherical mirror projection are most pronounced.



Fisheye Projection with truncated image

Fisheye projection image truncation gives more resolution but sacrifices the area at the rear of the dome.

Fisheye projection truncation can be used to make better use of the available pixels to increase brightness and resolution, but a substantial area of the back of the dome is lost as a result. In this scenario, around 30%.



Optimizing Spherical Mirror Projection

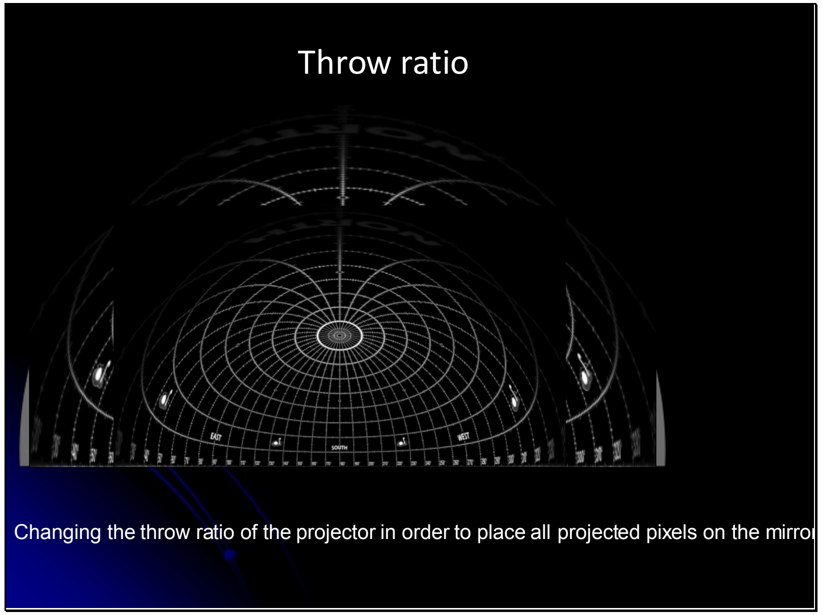
How do we get more resolution and brightness on the front of the dome using spherical projection?

How can we get more resolution and brightness on the front of the dome?

Unlike Fisheye projection, there is not a one-to-one relationship between the pixels used to cover a specific area in the rear of the dome and the pixels used in the front of the dome.

For example: the red area is used to project only about 7% of the rear of the dome. Yet it contains almost twice the number of pixels that are used to project the front 50% of the dome!

So, how can we manipulate a spherical mirror projection system to give up the extremely pixel rich but small area immediately adjacent to the mirror in the rear of the dome in such a way as to greatly increase the pixel density in the front of the dome?



Throw ratio

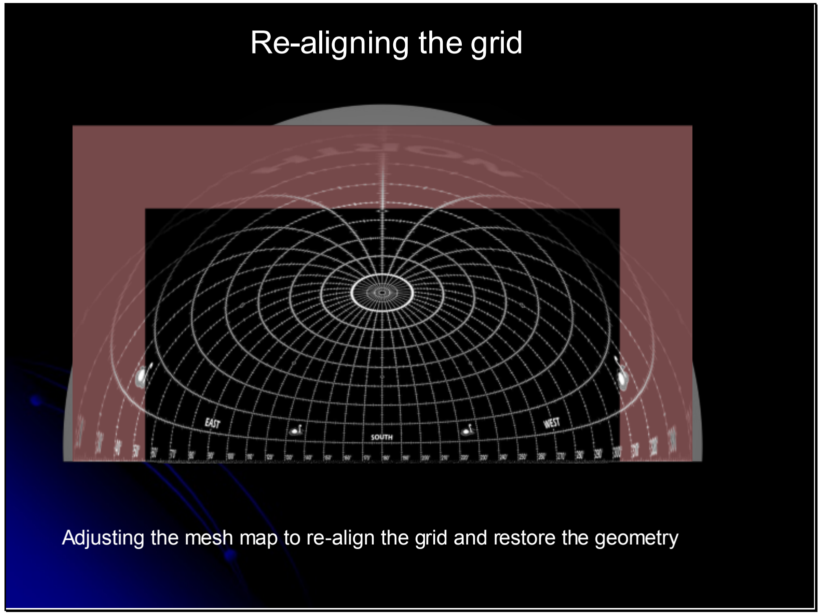
Changing the throw ratio of the projector in order to place all projected pixels on the mirro

Let’s take a look at a two step process for achieving this.

Here is the image projected on the spherical mirror in a standard configuration. Notice the grey areas on the top corners. These areas are not projected on the mirror and thus are not part of the intended projected image. Basically, wasted pixels.

By changing the throw ratio of the projector such that all pixels produced by the projector are placed on the mirror, we are able to greatly increase the number of pixels projected on the front half of the dome. Notice how the corners of the projection just touch the outside edge of the mirror. All the pixels are now in use.

This adjustment, done by itself, causes the standard warping map to be considerably mis-aligned. Let’s address this next.

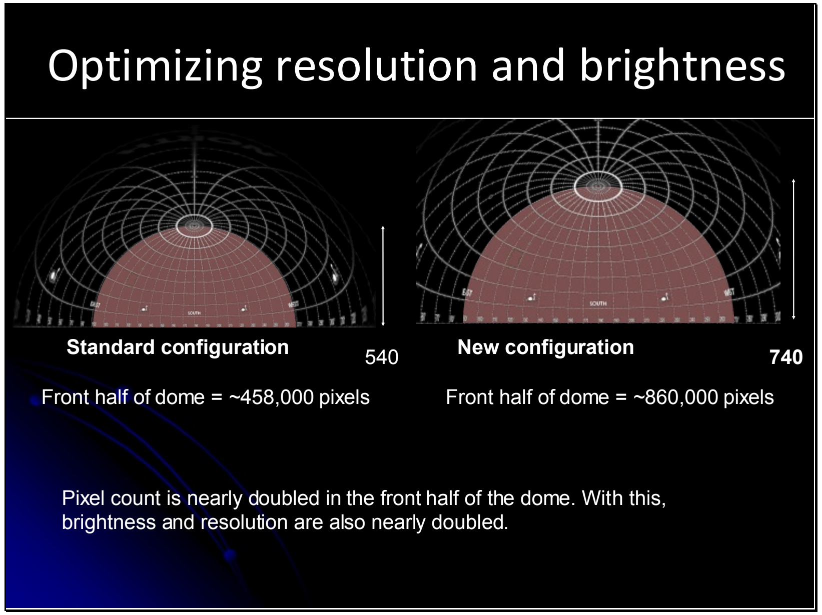


Re-aligning the grid

Adjusting the mesh map to re-align the grid and restore the geometry

Using Paul Bourke’s Meshmapper software program, a new warping map is created that re-warps the projection to make the images geometrically correct on the dome.

This new grid may look familiar. What we’ve done is: by not projecting the area in red (about 7% of the dome in the rear), we have nearly doubled the pixel density in the front half of the dome.



Optimizing resolution and brightness

Standard configuration 540

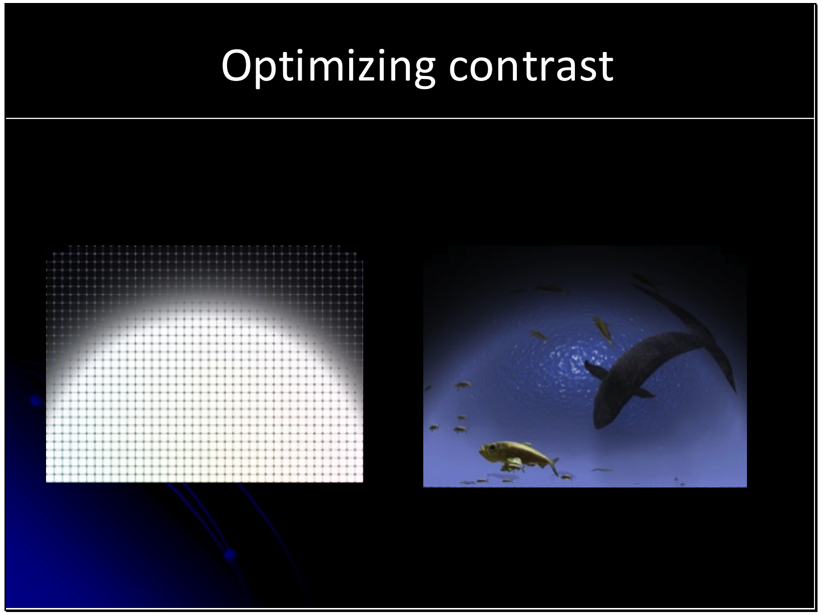
New configuration **740**

Front half of dome = ~458,000 pixels

Front half of dome = ~860,000 pixels

Pixel count is nearly doubled in the front half of the dome. With this, brightness and resolution are also nearly doubled.

The new configuration puts another 400,000 pixels in the front half of the dome while only giving up about 7% of the projection area in the rear of the dome. This nearly doubles the resolution and contrast in the front half of the dome.

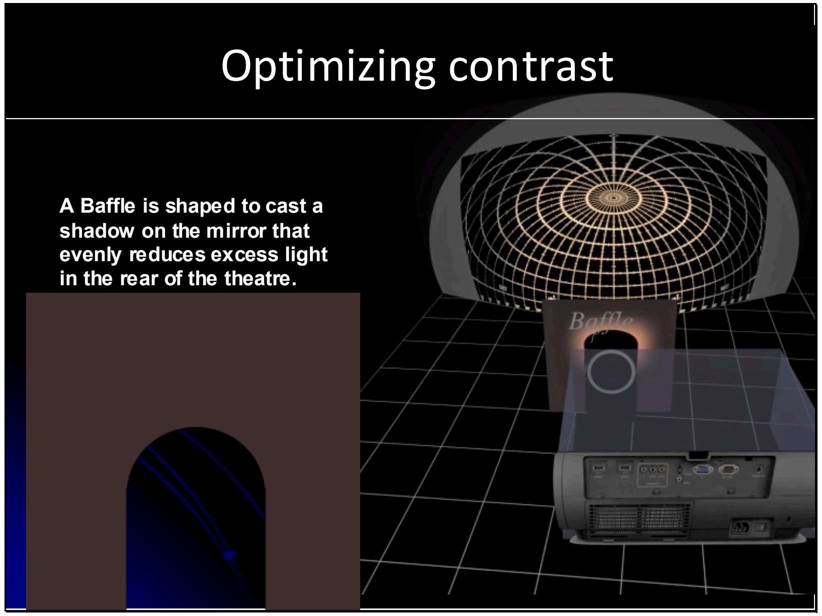


Optimizing contrast

A Spherical mirror system projects an unusually large number of pixels near the mirror in the back of the theatre. This causes problems with balancing the brightness between areas of the dome with different concentrations of pixels per given area.

This is usually accomplished by an option in Paul Bourke’s Meshmapper which applies a gradual dimming to pixels near the mirror in order to evenly project brightness over the whole dome.

In a large dome, the projector is extremely bright and even with the pixels dimmed nearly to black at the closest point to the mirror, the projected black is actually a bright grey. When projecting the night sky, we found the area around the mirror was still causing a problem in contrast on the rest of the dome.

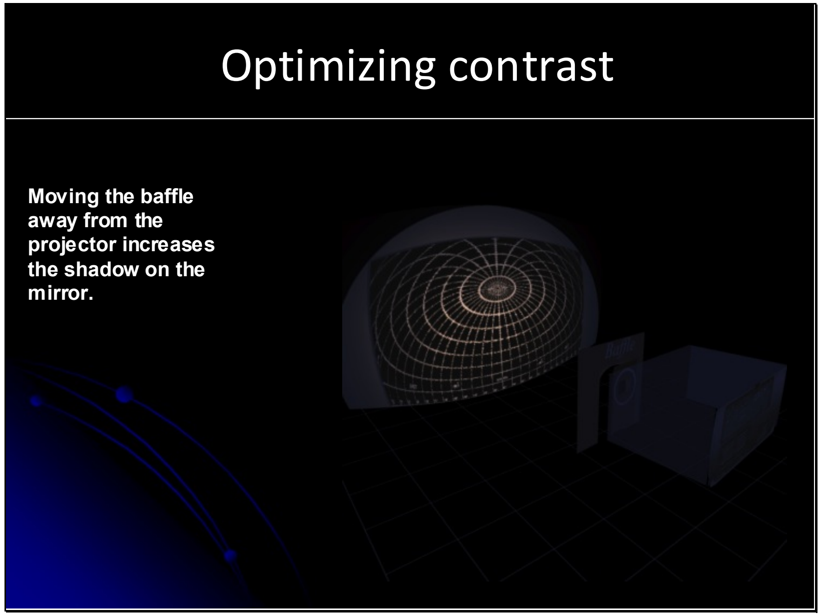


Optimizing contrast

A Baffle is shaped to cast a shadow on the mirror that evenly reduces excess light in the rear of the theatre.

We don’t use the option in Meshmapper to gradually electronically dim the pixels close to the mirror. We chose to use a mechanical baffle to accomplish the task of dimming the area associated with those pixels. Using this method, all levels of light are reduced equally in areas close to the mirror and contrast between light and dark are maintained. Conversely, with electronic dimming, the contrast is diminished between light and dark as a consequence of making the brightest light proportionally dimmer. Also, because the baffle dims all projector light near the mirror, less stray light is reflected on the remainder of the dome.

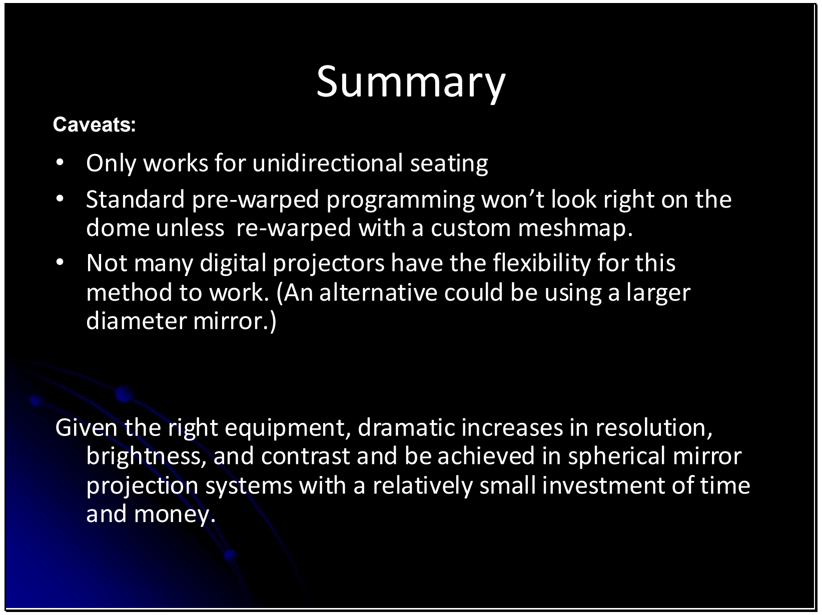
A specially shaped baffle is placed close to the projector lens. It blocks light from the tops and sides of the unfocused image. It casts a shadow on the mirror of a shape very similar to the effect produced electronically with Meshmapper.



Optimizing contrast

Moving the baffle away from the projector increases the shadow on the mirror.

The baffle can be set at different distances from the projector to adjust the amount of baffling. As the baffle is moved away from the projector, more of the light cone is intercepted and the shadow on the mirror becomes more pronounced.



Summary

Caveats:

- Only works for unidirectional seating
- Standard pre-warped programming won't look right on the dome unless re-warped with a custom meshmap.
- Not many digital projectors have the flexibility for this method to work. (An alternative could be using a larger diameter mirror.)

Given the right equipment, dramatic increases in resolution, brightness, and contrast and be achieved in spherical mirror projection systems with a relatively small investment of time and money.

In summary:

Some caveats:

- Obviously, this method is only going to work well with unidirectional seating.
- If you are buying your programming pre-warped, it won't look right unless re-warped with a custom meshmap.
- The Digital Projection dVision 1080 XL is used in the system at the Gottlieb. It incorporates a zoom feature which allows for a great deal of latitude in adjusting the throw ratio of the projector and is capable of focusing a very small image on the mirror. Not many digital projectors allow this much flexibility in image size and focus. One idea that might be explored to make this technique available to more projectors is using a larger diameter mirror.

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Special thanks to:
Rick Henderson
Jeff Rosenblatt
Jack Dunn

Thank you very much for the opportunity to present.