Introduction to digital fulldome technology

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Outline

- My background.
- Brief history.
- Fundamentals of all perspective projections: the camera model.
- Main dome configurations and implications.
  Main digital projection technologies and implications.
- CG (computer generated) content.
- Photographic content options.
- Filmed content.

- Photographic fisheye demonstration.
- LadyBug-3 camera demonstration.
- iDome demonstration in iVEC@UWA.

Personal background

- I'm not a filmmaker.
- Not even a fulldome content developer ... but I've dabbled.
- Initial work was in 2000 producing astronomy visualisation sequences for "Infinity Express", a SkySkan production.
- My main influence has been the invention of the spherical mirror projection system which is now in wide use around the world for small and/or low budget installations.
- Secondary influence has been in the joint development of the iDome in collaboration with iCinema (Interactive cinema) researchers at UNSW.
- Personally interested in the use of domes as immersive environments for science visualisation.

Very brief history of planetaria

- 1500BC: Earliest known depiction of the night sky on Egyptian tomb of Senenmut.
- 500BC: First known domed building, called the The Dome of Heaven.
- 1923: First planetarium built in Munich, Germany.
  Projection using the Zeiss Mark 1 star projector.
- 1949: Spitz demonstrated their first star projector at Harvard College in the USA.
- 1959: First planetarium and star projector by GOTO of Japan.
- 1965: First star projector by Minolta of Japan.
- 1973: First OmniMax (iMAX) opened in Reuben Fleet Science Centre, based upon 70mm film.

Brief history of digital fulldome

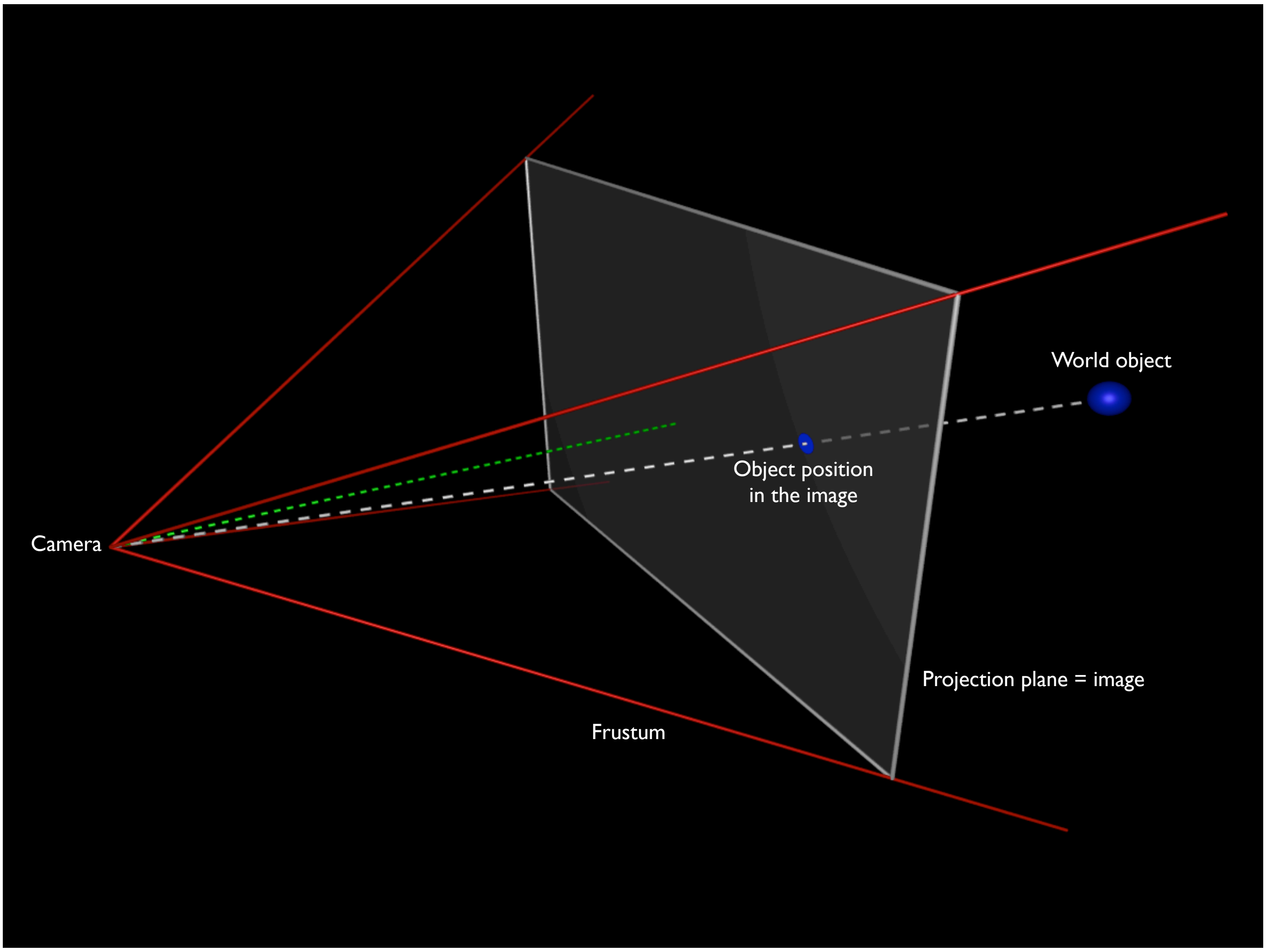
- 1983: Evans and Sutherland develop a vector graphics style projector capable of creating points and lines at the Virginia Science Museum.
- Alternate Realities released the VisionDome in 1994.
  Elumens produced "personal domes", primarily as simulators for the military.
- 1997: Spitz install the first ElectricSky system in Canada comprising of 4 CRT projectors and edge blending.
- 1998: SkySkan demonstrates their digital projection system.
  The first digital video content not reliant on custom projection hardware.
- 2002: First laser projection system by Zeiss demonstrated in the largest digital dome at the time, 24m diameter.
- 2005: GOTO of Japan create the first full sphere projection system.
- 2008: SkySkan installs the first 8Kx8K projection system in the Beijing planetarium.
- 2010: SkySkan installs first stereoscopic 8Kx8K planetarium in Macau.

Immersion and peripheral vision

- Peripheral vision is one of the capabilities of our visual system that is not engaged when looking at standard flat or small displays. (Similarly stereoscopy, sense of depth arising from our two eyes, is another unused capability).
- For all practical purposes our horizontal field of view is 180 degrees, vertical field of view is approximately 120 degrees.
- Note we don't necessarily see colour or high definition in our extreme horizontal field, it has evolved to be a strong motion detection mechanism. Our visual system does "fill in" the colour information for us.
- A hemispherical dome allows our entire visual field (vertically and horizontally) to be filled with digital content.
- We are used to seeing the frame of the image which anchors the virtual world within our real world. In a dome one often doesn't see that reference frame.
- The "magical" thing happens when one doesn't see the dome surface, more common in high quality domes with good colour reproduction. Our visual system, without any physical world frame of reference, is very willing to interpret representations of 3D worlds as having depth.

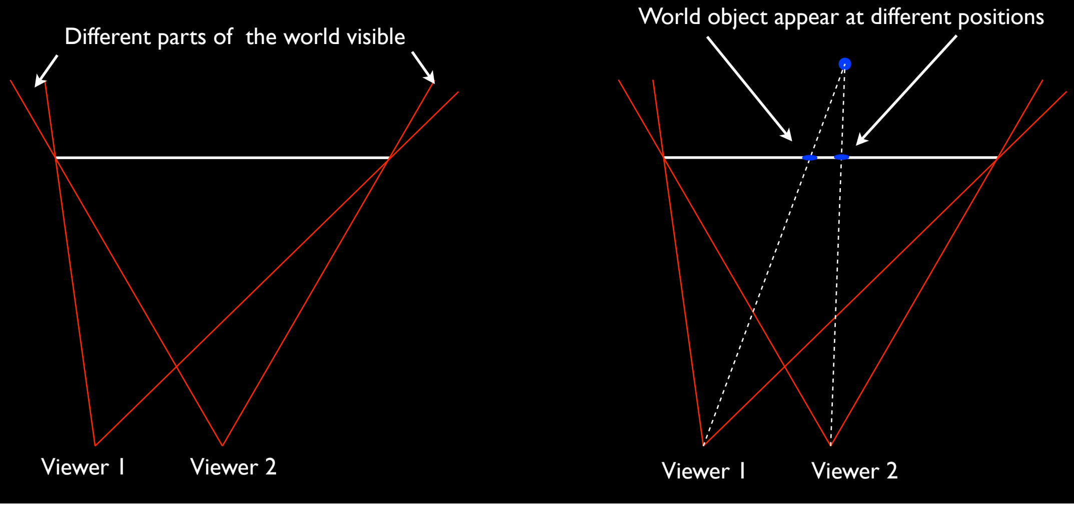
Basic projection theory

- Useful to think about the (idealised) camera model used in computer graphics for virtual reality and immersive environments.
- Camera = Observer.
  Projection plane = Screen surface.
- Standard perspective projection, draw a straight line from the camera/observer to a point in the world, where the line intersects the projection surface is where it appears on the screen surface.



Basic projection theory

- Implication is that all observers get a distorted view of the imagery except the one observer located at the camera position.
- We are tolerant of this for flat imagery, becomes more important for stereoscopic 3D and immersive environments such as domes.
- For example, in a dome straight lines will only appear exactly straight for observers located in the spot of the camera (sweet spot), generally the center of the dome.
- It is possible to place the sweet spot anywhere, but still the imagery is only strictly correct for an observer at that position.



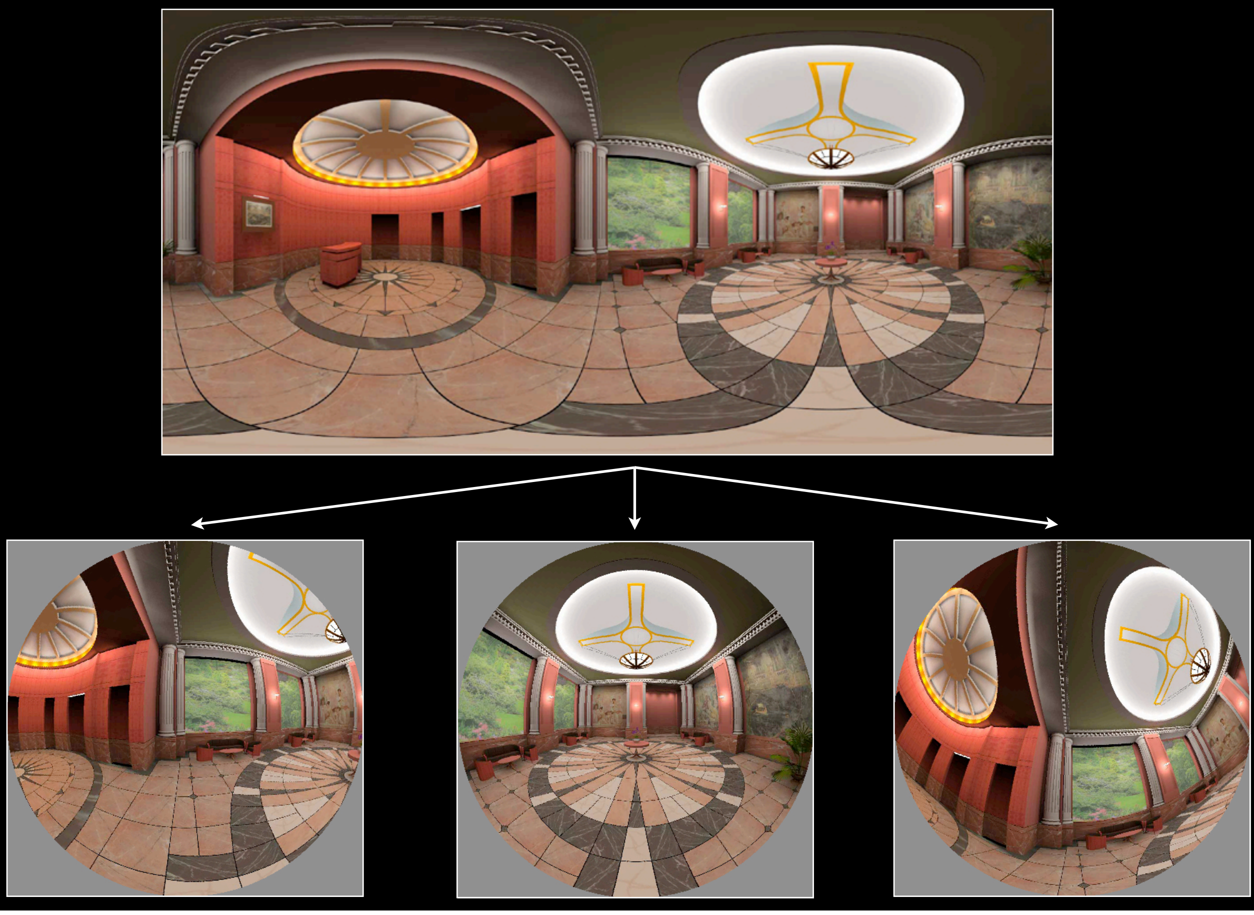
Fisheye projections

- While a standard perspective projection (rectangular frustum) is the natural projection for a flat rectangular image frame, the field of view cannot be widened to 180 degrees to produce the imagery required for a hemispherical dome.
- Same principle as for a flat screen, the dome surface acts as the window to the world. The intersection on the dome surface of a line from the camera/viewer to an object is where that object appears on the dome and consequently on the fisheye image.
- A fisheye projection is the natural way to represent the imagery for a hemispherical display.
- A fisheye projection is not limited to 180 degree FOV but becomes increasingly inefficient as the FOV increases.

Spherical projections

- Introduced now and discussed later in the context of the LadyBug-3 camera.
- A spherical projection is one possible unwrapping of a sphere. The image contains everything in the world that is visible, unlike a 180 degree fisheye that contains half the world.

One spherical projection = infinite fisheye images



Dome types and implications

- Omnidirectional or directional seating.
- Dome orientation.
- Dome construction.
  - Inflatables
  - Hard shell
  - Steel mesh
- Projection technologies.

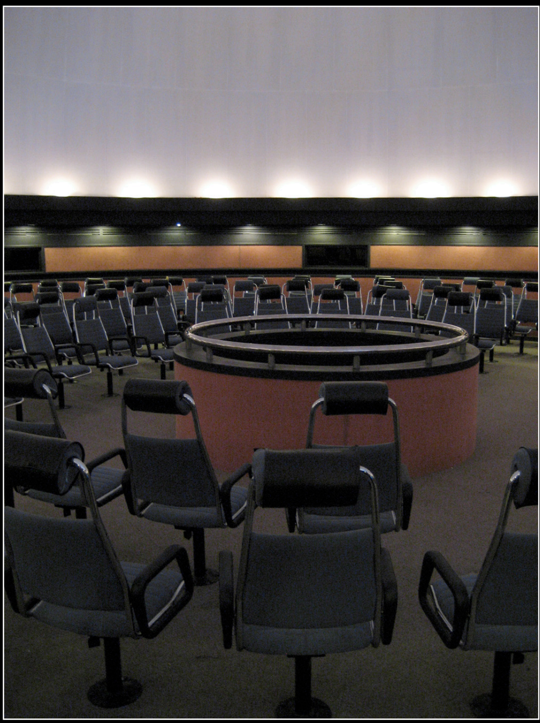
Seating arrangements and implications

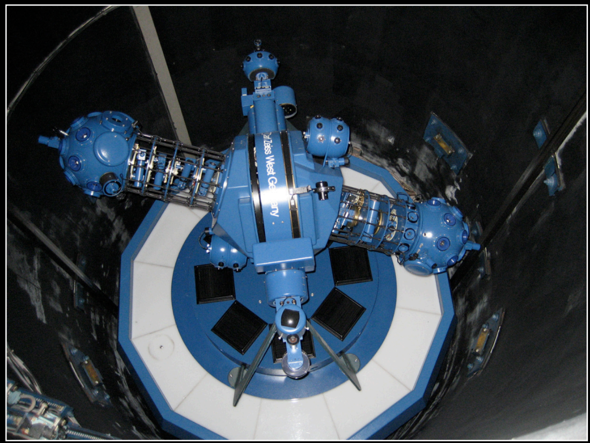
- Omnidirectional.
  This has been the most common arrangement in planetariums arising from their traditional emphasis on astronomy / night sky material.
- Unidirectional.
  More common in new planetariums, and in domes designed originally for movie content.

- Omnidirectional planetariums that have been fitted with digital projection can be a challenge for content creators, there needs to be interesting action everywhere.
- Content for omnidirectional domes is generally designed for a centre of attention (sweet spot) forward and 30 to 40 degrees above the spring line.

- Other considerations include the distance from the viewer to the spring line and the degree of tilting in the seating. This determines where the resting direction for the viewers head is.

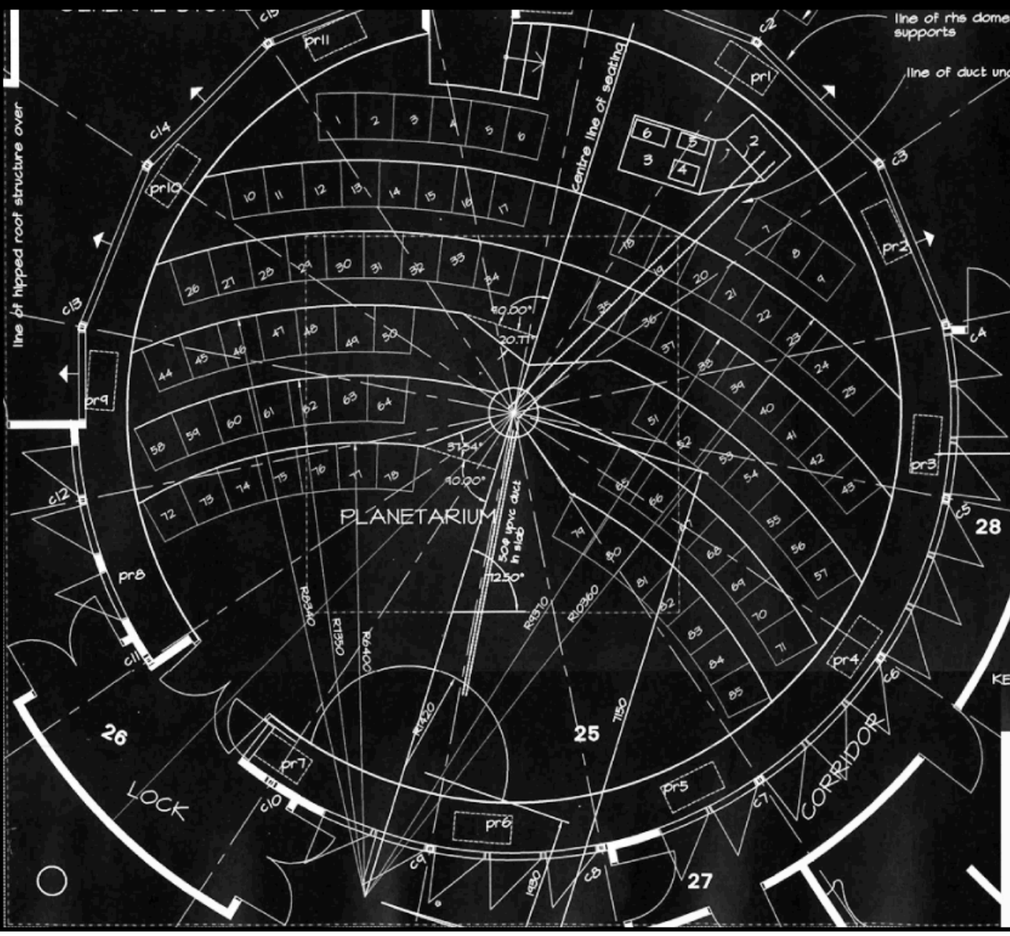
Traditional omnidirectional seating around a optomechanical projector





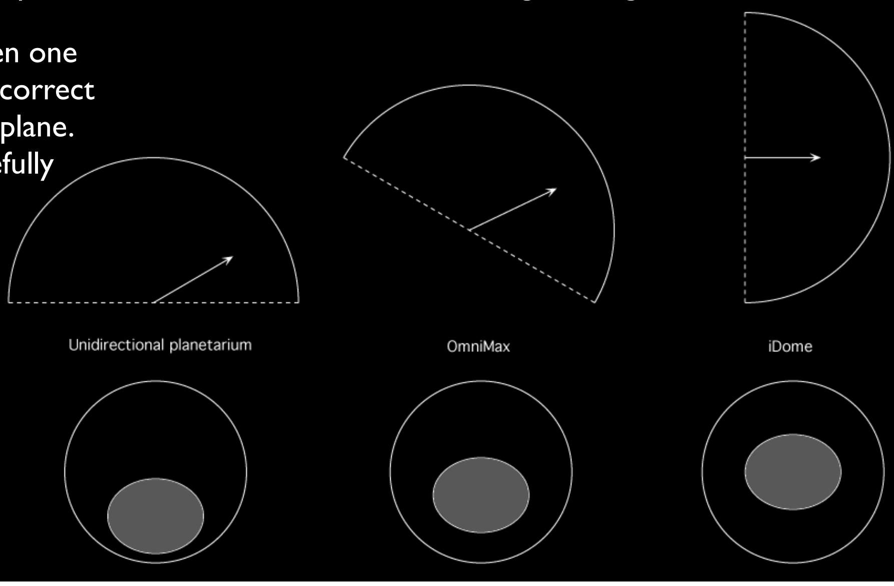
Kuching planetarium, Malaysia

Typical unidirectional seating



Dome orientation and implications

- Orientation:
  - Planetarium: 0 degree orientation.
  - Tilted (eg: iMax): most commonly 30 or 45 degrees.
  - iDome: 90 degrees.
- This does affect the sweet spot for the action for directional seating/viewing.
- Particularly important when one is attempting to present a correct appearing ground/horizon plane. Since the observer is hopefully immersed in the scene, an angled horizon can feel unnatural.
- Content developers want to create material with the widest possible distribution.



Courtesy Giorgio Marchetto

Horizon effects

- A problem for traditional horizontally orientated domes.
- Tilting the world leads to a somewhat unnatural experience.
- Tilted domes can represent a correctly orientated horizon.
- Particularly important for directed forward motion and horizontal panning.
- One solution by some practitioners is to render greater than 180 degrees.

180 degree fisheye

220 degree fisheye

Bassano
Courtesy Georgio Marchetto

Inflatable domes

- Wide range of dome sizes from 3m to 30m (and larger).
- More often small domes with limited space and setup time, not usually suited to multiple projectors.
- Very difficult to get a seamless (invisible) surface on inflatable domes.
- Dome surface needs to have limited reflectivity for digital projection, grey not white.

5m inflatable

30m inflatable

Hard shell transportable domes

- Rarely greater than 6m in diameter.
- Often used as preview environments.
- Generally have “interesting” acoustic properties.

Courtesy Mirage3D

Courtesy Company-in-Space

Surface based domes

- Often easier to build on a small budget but the seams between the panels are almost always visible.
- Often based upon Bucky ball or geodesic geometry for aesthetic or structural reasons.

3m

Toongabble school, Sydney

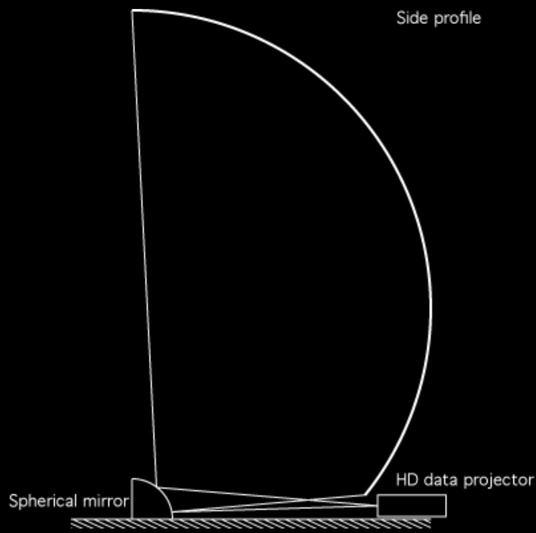
20m

Gravitational discovery centre, GinGin, WA

iDome

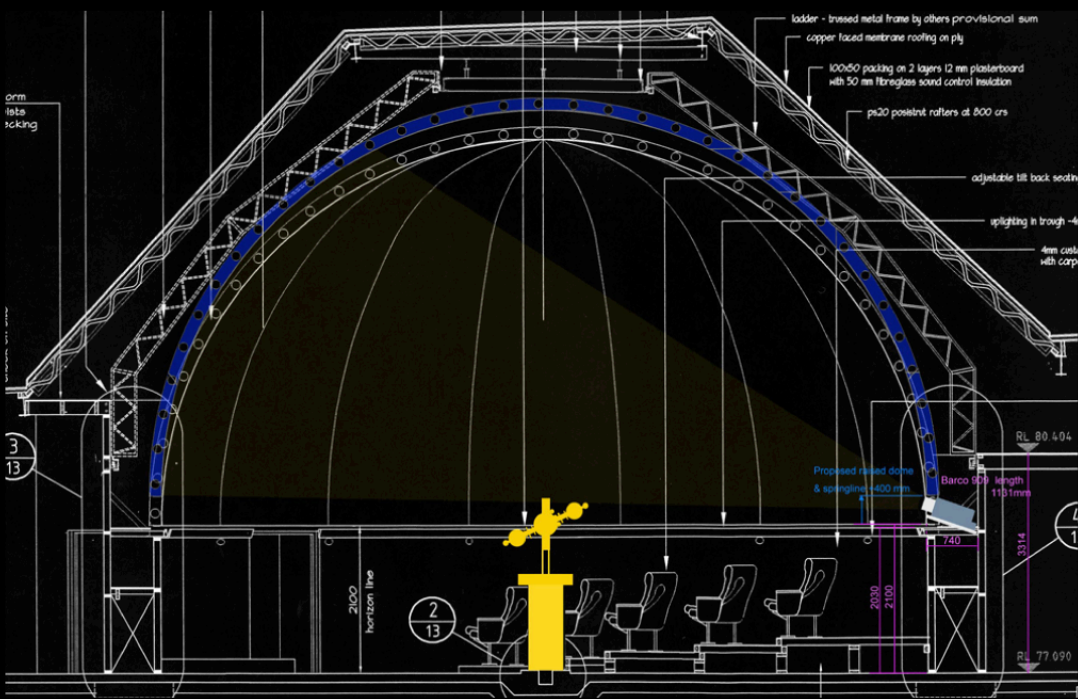
- A small, personal, upright hemispherical surface.
- So small that a fisheye projector would occupy the space required by the viewer.
- Spherical mirror conveniently locates the projector behind the base of the dome.


Courtesy Giorgio Marchetto



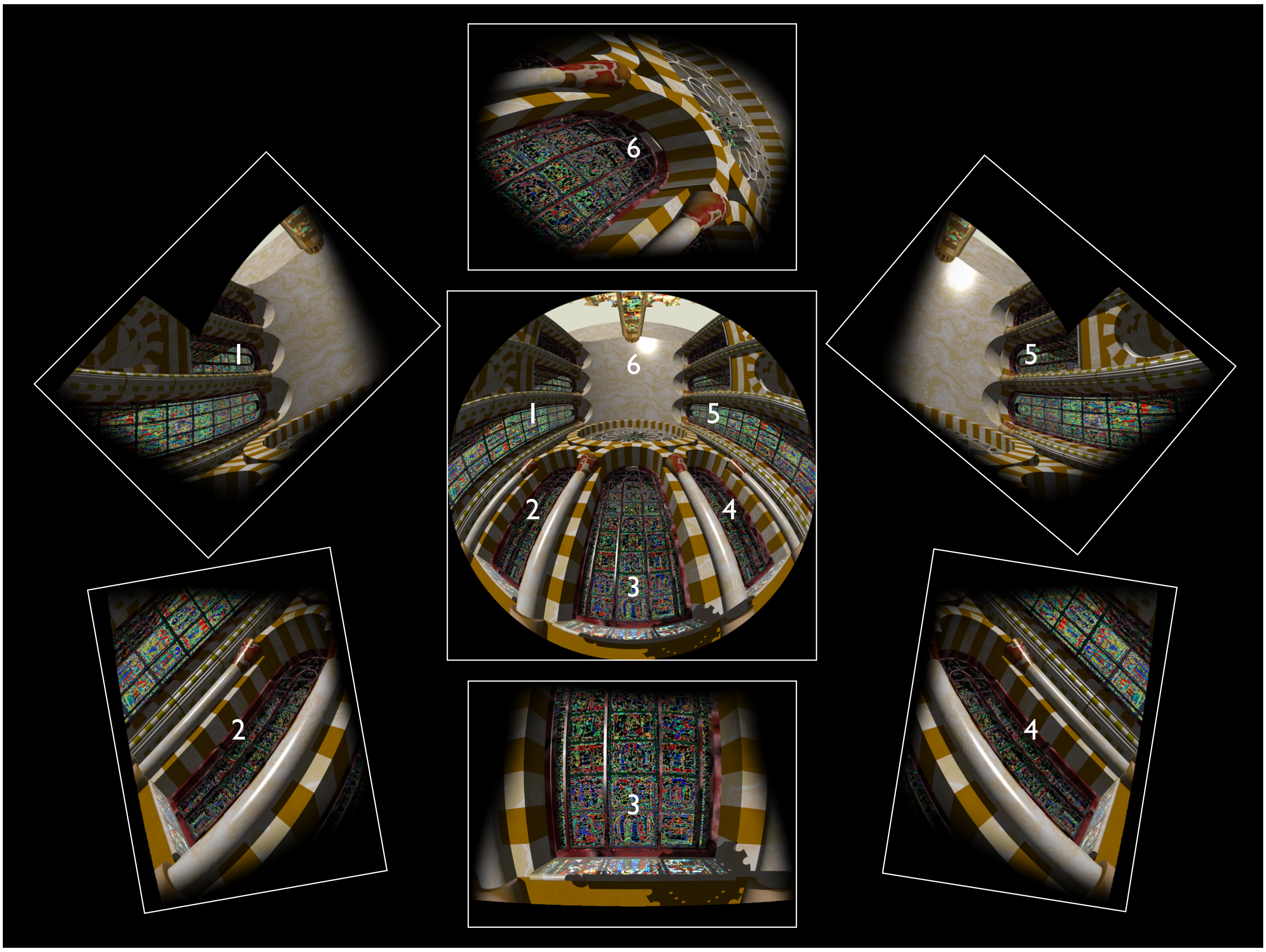
Fixed domes

- Generally perforated steel.
  Perforated for control over reflectivity, improved acoustics, and sometimes airflow.



Projection technologies and implications

- Some knowledge of the available resolution is relevant since it defines the finest detail that can be resolved.
- Multiple CRT projectors are the traditional approach to achieving high resolution and brightness, most commonly 5 or 6.
- Each covers a part of the dome and images edge blended together.
- Generally have the highest installation cost and cost of ownership.
- Fisheye image frames get sliced up and optionally warped into N pieces, N = number of projectors employed. The exact geometry depends on the installation.
- In the past they have had the best black levels and colour space.
  Historically since black was important in planetariums it was necessary to use projection technologies that allowed very good blacks, namely CRT projectors.
- Can be a bit "soft" due to analog nature of CRT.
- The edge blend zones are inevitably out of focus.



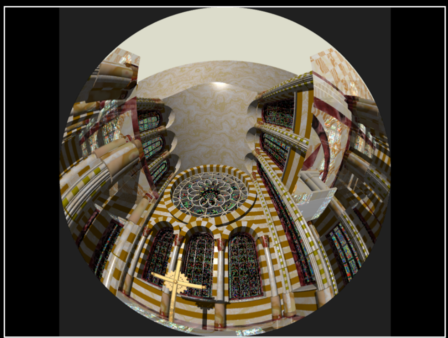
Multiple digital projectors

- Currently most suppliers are using digital projectors.
- Edge blending quality is highly dependent on black levels.
- Edge bending issues, largely determines the "effective resolution", not the same as the maximum resolution of the system.
  - Alignment precision, mechanical changes over time.
  - Blurred effect across boundary since alignment is rarely pixel perfect.
  - Colour variation between projectors.
  - Colour variation as projectors age.
- Two main approaches
  - Multiple (again usually 5 or 6) digital projectors.
  - Small number (often 2) higher resolution projectors. Sony 4K currently very popular.
- Starting to see stereoscopic installations, out of the scope of this workshop.

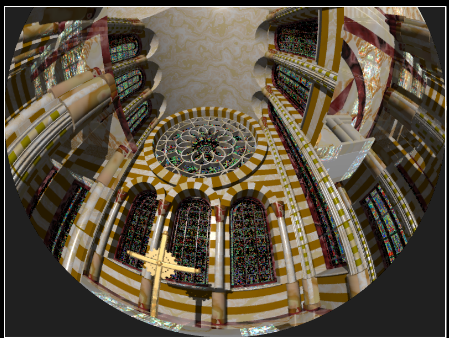
Single fisheye or twin fisheye

- Third main approach are small twin projector units with partial fisheye lenses, single projector with fisheye, single projector with spherical mirror.
- Single projector system are most common in small or portable domes due to their space savings and short setup/calibration time.
- For true fulldome a circular fisheye makes inefficient use of a 4x3 or 16x9 aspect of digital projectors. One compromise is to truncate the fisheye to get better pixel efficiency at the expense of less image at the back of the dome.

Inscribed fisheye in a 4:3 frame



Back truncated fisheye



Single fisheye or twin fisheye

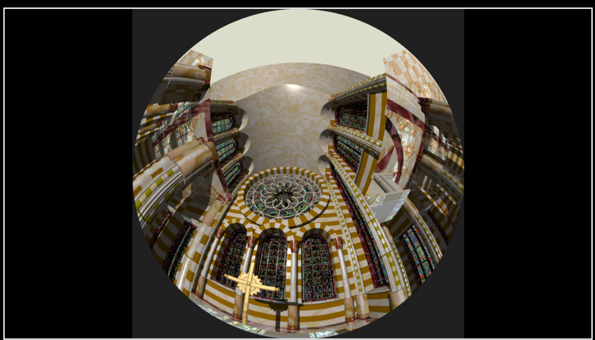
- Main issues are:
  - Chromatic error towards the rim (Depend on fisheye lens quality).
  - Not insignificant light loss through a large piece of glass.

Digitalis

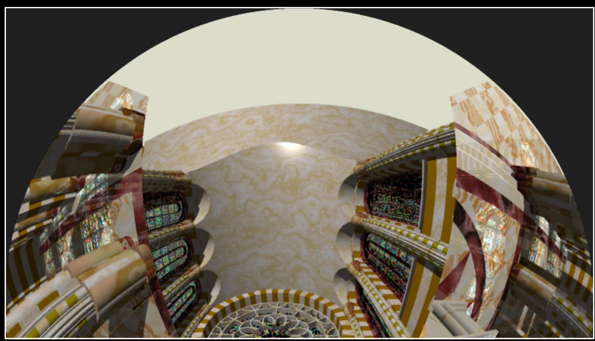
Definiti Twin, Zeiss

Single fisheye or twin fisheye

- Even less efficient for current 16x9 aspect projectors, 44% of the pixels.
- Ideal for twin projectors.
- Truncated fisheye uses 80% of a HD sensor.



Inscribed fisheye in a 16:9 frame

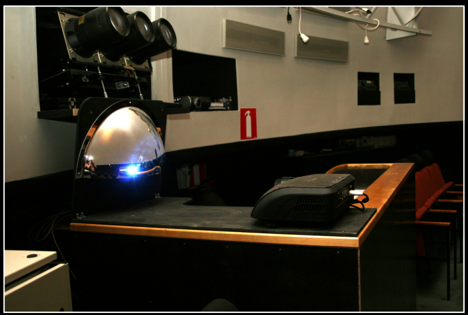


Twin fisheye pairs in a 16:9 frame

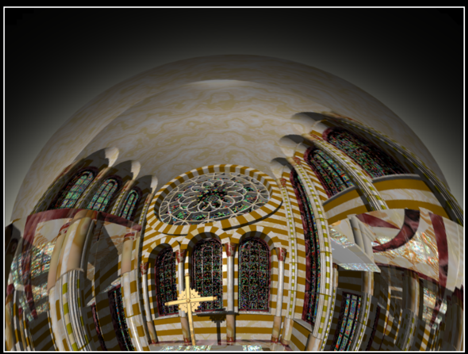
Spherical mirror

- My invention, originally for low cost projection for portable domes.
- Currently competes with all but the top end of the single fisheye solutions.
- The usual metrics for evaluating dome resolution don't apply. Doesn't make sense to talk about pixel usage or efficiency because unlike a fisheye lens system there is more variation in pixel sizes on the final dome.
- Common to require a intensity mapping as well to compensate for the different light paths and pixel densities.
- The exact warping is generally derived by a simulation application that takes all the physical parameters into account and creates a mesh with the correct texture coordinates onto which the fisheye images are applied.
- As with fisheye lens one attempts to use as many pixels as possible, in general 16:9 projectors are a better fit.
- Suited to smaller domes because the hardware occupies space on the edge of the dome, similarly for upright domes.

Spherical mirror



Courtesy Sarah Kenderdine



Typical planetarium warp (4:3)

Example for an upright dome

Projection technologies and implications

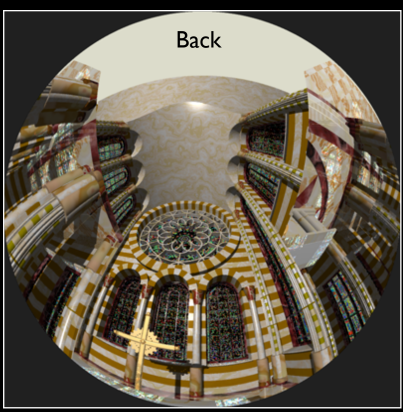
- The main implication is around the resolution the different system can present on the dome surface.
- Expectation by planetariums who have invested in high end systems to receive material at that resolution.
- Small planetariums with a low end fisheye system may not be able to represent more than a 1K square fisheye. Many installations will ask/expect between 3K and 4K fisheye images. Some sites today can present 8K square images.
- Note that details visible in a 4K images may not be visible on a 1K projection system.
- Difficult to compare resolution between some technologies, the systems quoted resolution is generally not the same as the actual available/perceived resolution.
- Important to realise that in all cases content is supplied as fisheye images, anything that needs to be done to those to make them playable is the responsibility of the installation. Generally only they will have the software and the calibration information necessary.

Some standards

- 30fps is the norm (actually 30, not 29.97 of NTSC)
- Orientation of the fisheye frame, see image bottom-left.
- Unfortunately no good gamma or colour space specifications (gamma, white point, temperature).
- Audio requirements are quite variable between installations, from simple stereo in small domes to 7.1 systems.
- Not uncommon to place information within the unused portions of the circular fisheye frame. Eg: frame number, sequence name, author ... no standards.

Back

Left



Right

Front

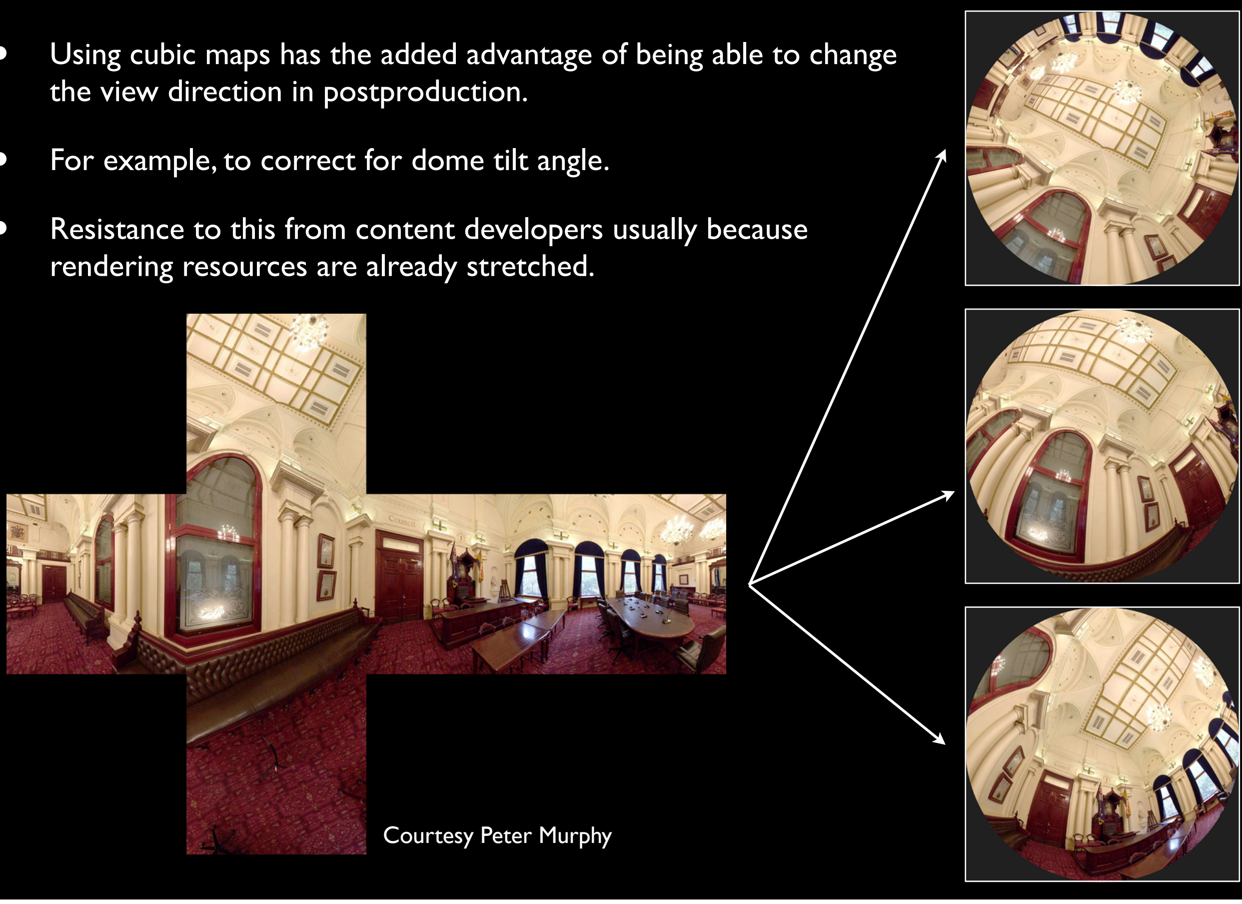
Computer generated fisheye

- Most animation/rendering packages support a circular fisheye lens or there is an external plugin.
- Where this isn't the case the most common approach is to render cubic maps and post process those to form a fisheye.
- Can choose to render between 4 and 6 faces of the cube to and postprocess to generate a fisheye.
- See "cube2dome", my stitching software, "Glom" from Spitz, and others.
- An implication to animators is they need to model more of the world than they might normally do because of the wider field of view.

Courtesy Peter Murphy

Computer generated fisheye

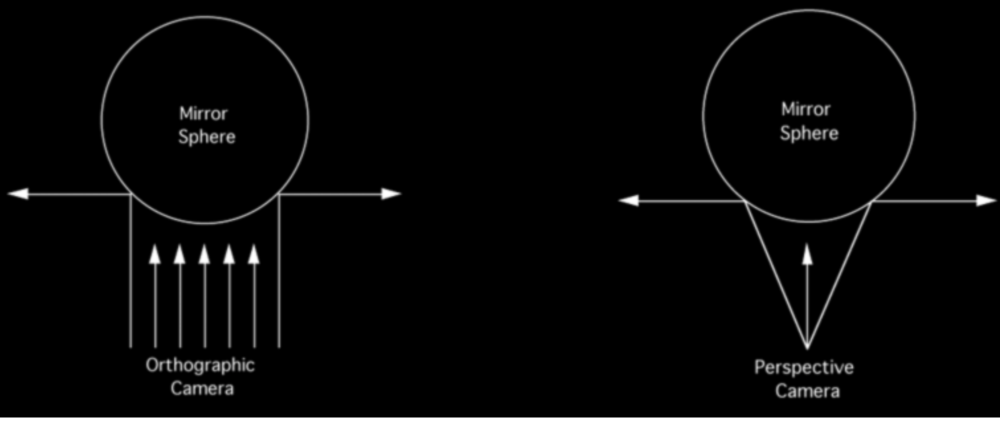
- Using cubic maps has the added advantage of being able to change the view direction in postproduction.
- For example, to correct for dome tilt angle.
- Resistance to this from content developers usually because rendering resources are already stretched.



Courtesy Peter Murphy

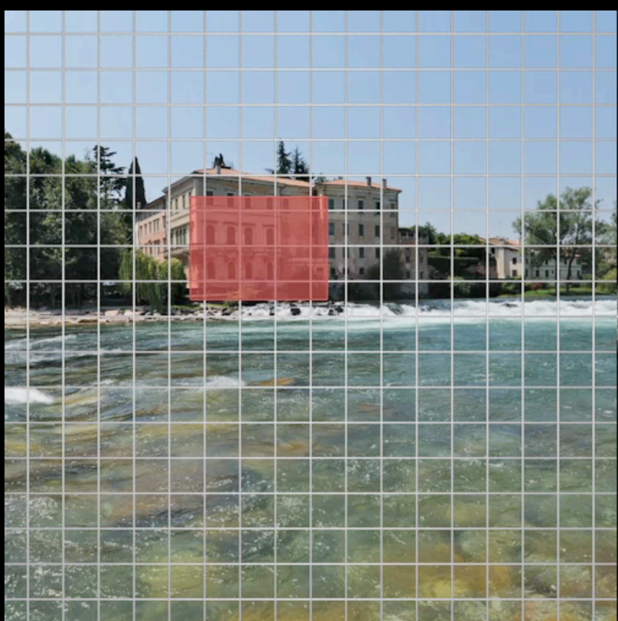
Approximations

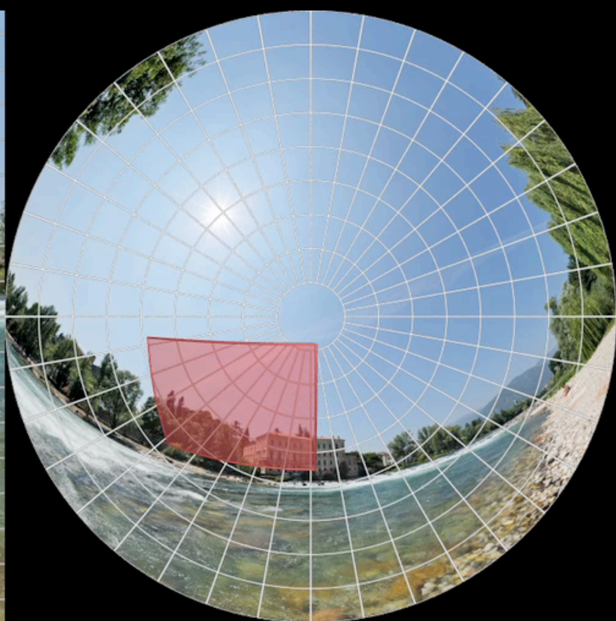
- An approximation to a fisheye can be achieved by rendering with a perfectly reflective sphere in front of the virtual camera.
- This has been used by animators when there isn't a native fisheye lens supported. Can be a messy approach. Need to be very careful that objects don't come between the camera and the mirror, similarly shadows cast on or by the mirror.
- "Very close" but not strictly correct, I doubt many people can tell in a large planetarium due to the errors caused by not being at the dome center. It is possible to post process the fisheye such that the result is a true fisheye but that hardly worth the effort.
- Not very common or necessary today due to limitations and availability of other methods.



Editing and compositing

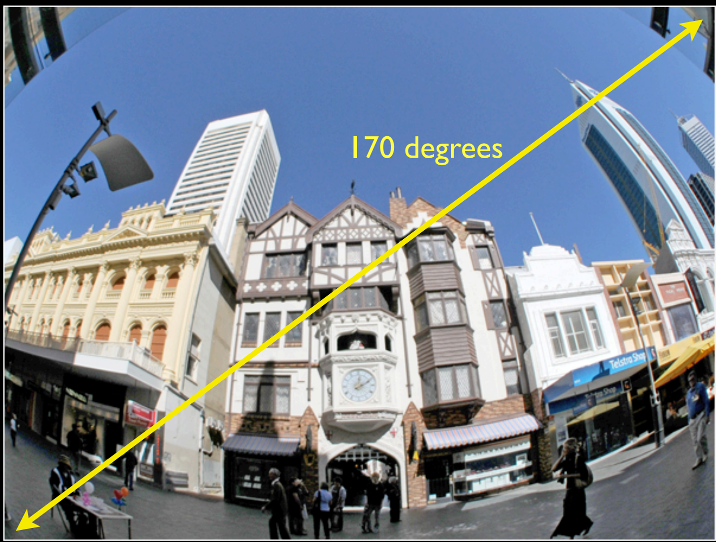
- "Fisheye aware" plugins to various compositing packages are available.
- The "problem" is that it is difficult to use standard compositing packages because the coordinate system for fisheye is very different to the normal rectilinear coordinates of traditional film.





Fisheye photography

- Simplest way is a single (usually SLR) camera and fisheye lens.
- Distinction between wide angle fisheye lenses and circular fisheye lenses.
  For example a 175 degree wide angle fisheye is usually the angle between the diagonals.
- As with fisheye lenses on projectors, the main issue is detail and chromatic error at the rim.

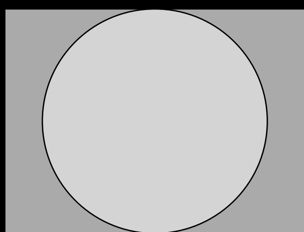


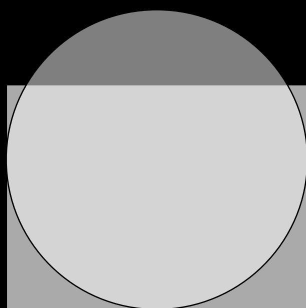
170 degree wide angle fisheye


Circular fisheye

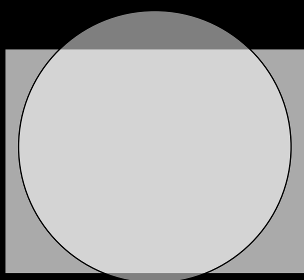
Introduction to fisheye camera lens

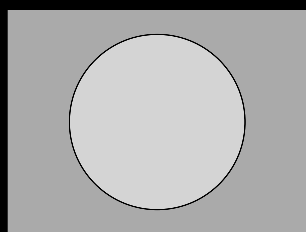
- Consideration of how much of the sensor is being used or if the fisheye is truncated.
- Introduce the Nikon D300 and Sunex lens,
  or the Canon 5D MkII and Sigma lens.
- Limited by the vertical resolution.


Optimal


Optimal for truncated projection


Truncated fisheye (top and bottom)


Too large

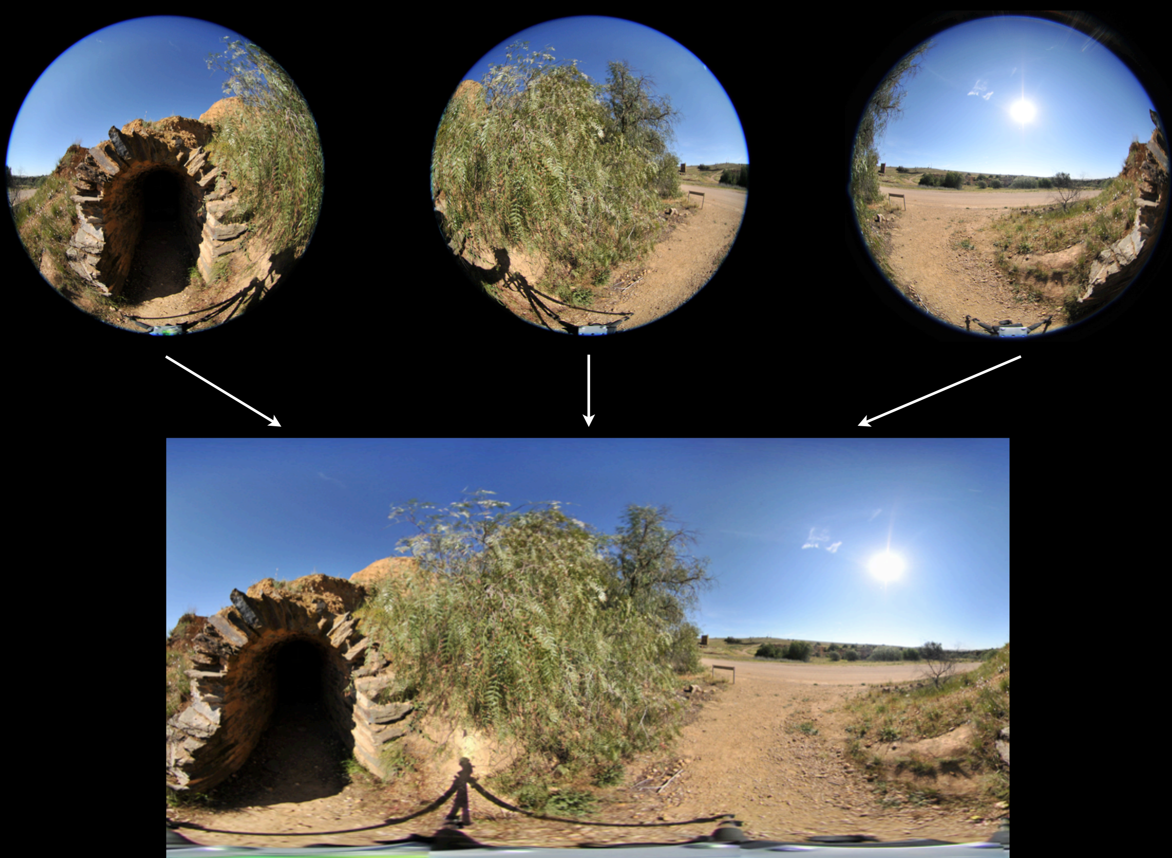

Too small (Inefficient)

Cameras available at this workshop

Nikon D-300 and Sunex fisheye lens

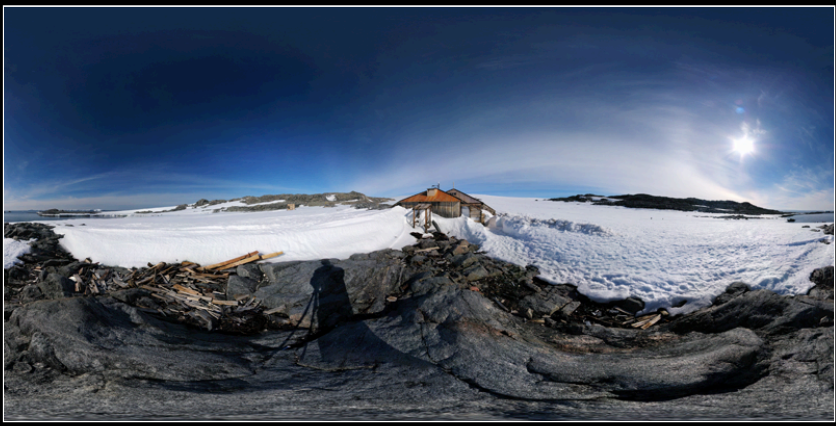
Canon EOS 5D MkII and SIgma 8mm fisheye lens

Spherical projections from fisheye lens



Spherical projections from gigapan

- Higher resolution spherical panoramic images can be acquired using a large number of shots.
- One takes multiple overlapping images at different latitudes and longitudes. These are stitched together and blended to form a single seamless spherical projection.
- This can be automated with devices such as the Gigapan mount.
- In general a regular scan in longitude and latitude is performed even though this is inefficient towards the north and south pole.



Mawsons hut (Antarctica), courtesy Peter Morse.

Fisheye filming

- Much more difficult to achieve the resolution expected by some installations.
- For directional seating truncated fisheye can give better results.
- Note that resolution is not solely related to sensor resolution, video camera apply lossy compression.
- Fisheye lens can be mounted on some video cameras but still difficult to find a high quality solution. Commodity video cameras are at most 1080p which limits the diameter of a full fisheye.
- Full fisheye vs partial fisheye, same issues as with fisheye projection: truncated or inscribed fisheye. Partial fisheye circles may be acceptable for domes with directional seating.
- Issues of lens quality, chromatic error and focus issues on the rim.
- Same issues with fisheye image and sensor size as discussed with still cameras.

Canon HV20 HD 1080p

Truncated top and bottom

In the iDome

Introduction to the LadyBug cameras

- Captures a full 360 degree field of view horizontally and about 145 degree field of view vertically.
- Capturing more than we need but it means we can choose the exact the exact fisheye view in post production. Same advantages as discussed for cubic maps for computer generated material.
- Resolution of the spherical projection is 5400 x 2700 pixels. Translates into fisheye images around 2000 pixels square. This does not take into account the video style compression artefacts that occur.
- Limited to 16fps. The earlier LadyBug-2 was 30fps but lower resolution.

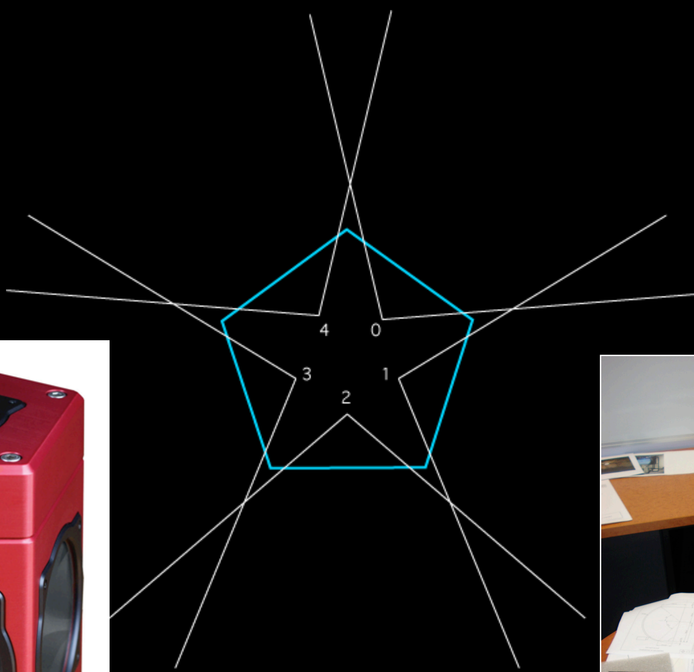
Spherical projection

Courtesy Volker Kuchelmeister, iCinema

One possible derived fisheye

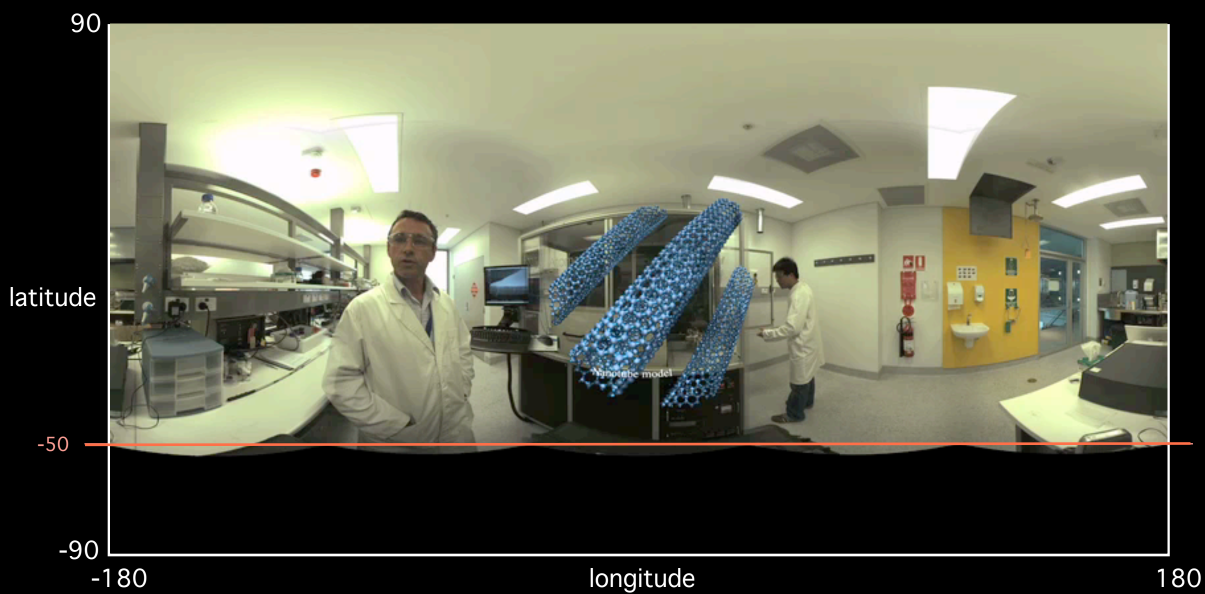
LadyBug-2

LadyBug-3



LadyBug-3

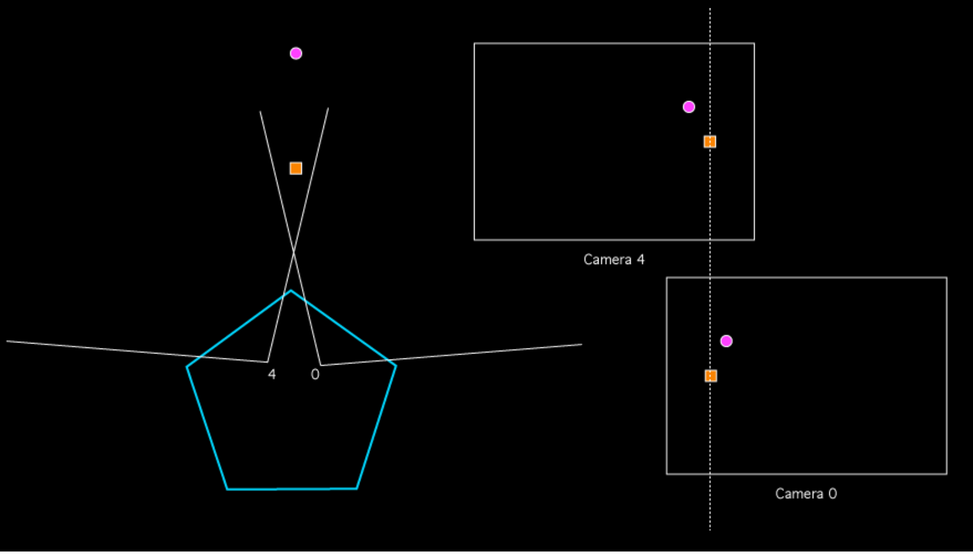
- Captures 360 degrees horizontally (longitude).
- Captures from the north pole to approximately -50 degrees vertically (latitude).



LadyBug-3

- Some blurring on the camera seams.
  For fundamental reasons (out side the scope of this discussion) it is impossible to have a perfect seam at all depths. It is possible to have a perfect seam at one particular depth.

- Using the LadyBug-3 at full resolution in the field requires
  - Power source, eg: car battery.
  - Inverter to get AC from DC battery.
  - External fast hard disk.
  - Laptop.



Other 360 camera options

- Current solutions are generally unwieldy.
- Require mains power and large hard disk arrays.
- Stitching errors increase as the radius of the unit increases.

iCinema

iCinema

Micoy

Miscellaneous

- Compared to traditional film one needs to move objects around more slowly.
  A consequence of increased immersion.
- Similarly smooth camera movement is important (avoiding hard camera stop/start).
- Light is reflected of the dome surface onto other parts of the dome (not just to the audience as is the case on a flat screen), so very bright areas will tend to lower contrast across the whole dome. The degree to which this is a problem depends on the projection technology and installation.
- 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 so that minimal head panning is 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.

Comments / discussion / questions

Demonstrations in the iDome and the inflatable dome.

Courtesy Martin Ford

Courtesy Sarah Kenderdine