Digital Fulldome
Techniques and Technologies

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Outline

- Brief introduction and history of fulldome.

- Perspective projection and fisheye projection. The correct mental model for what's going on. Mathematics of the fisheye projections, the sweet spot and implications (Offaxis projections).

- Immersion and peripheral vision. The "magic" of fulldome.

- Rendering techniques: fisheye, cubic maps, and approximations.

- General (evolving) standards in the industry.

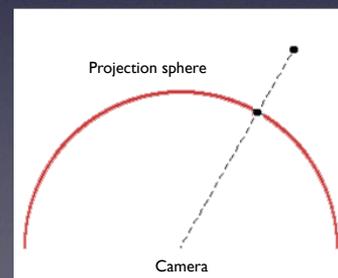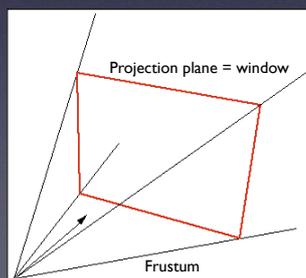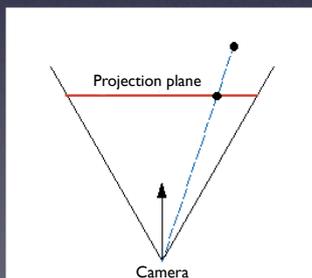- Challenges for fulldome developers.

  Break

- Projection technologies: Multiple projector, single/dual projector fisheye, spherical mirror. Relative merits and applicability of each.

- Variations between installations: Domes and seating, fixed and inflatable, seating configuration, tilt angle, resolution, colour space, dome surface, ...

- Live capture and realtime applications.

- Closing remarks and discussion. Welcome to discuss further after lunch and demonstration.

Brief introduction and history

- First (commercially available) digital full dome system is probably a CRT based Digistar around 1979. Granted it was black and white and clearly targeted at projecting points (stars).

- GOTO had a fulldome colour multiple projector CRT based system in 1996.

- Konica Minolta had a single projector fisheye lens based full colour system in 2000.

- Alternate Realities released the VisionDome in 1994. Elumens produced "personal domes", primarily as simulators for the military.

- Majority of countries have at least digital fulldome theatre, or are actively contemplating one.

- Many hardware offerings now from perhaps a dozen suppliers.

- As planetariums have embraced fulldome digital projection so has the content been able to move away from pure astronomy. Applications now range from the wider fields of science education, general visualisation, entertainment, virtual reality, and artistic expressions.

- As a consequence there is some confusion as to how the fulldome community identifies itself: virtual reality installation, immersive cinema, digital dome, ... certainly not just a planetarium.

- Creating content for digital fulldome is not something potential content creators have been trained in, it generally isn't covered by existing digital media or computer science courses.

Perspective projection and fisheye projection

- Most in the computer graphics industry are familiar with a perspective projection. To determine where any point in the world appears on the projection plane, draw a straight line from the world point to the camera. Where it intersects the projection plane is where it will appear on the image plane. Applies to both projection of virtual worlds and captured material.

- Correct way to think about this is: "the screen as the window on the world".

- In a hemispherical dome the projection plane is now a hemisphere but the same concept applies. An object in the world appears at the point where a line from the object to the camera intersects the hemisphere. This is an "angular fisheye" projection, also sometimes called "equidistant polar" projection since there is no resolution variation with latitude.

- Important to distinguish between the projection system and the camera/eye. The fisheye projection only refers to the camera/eye position, the position at which an observer gets a strictly correct view of the world. The projection system plays no part in this.

Projection plane — Camera

Projection plane = window — Frustum

Projection sphere — Camera

- Fisheye projection continued ... the details.

- Typically need to relate the mapping to/from fisheye image coordinates (2D) to a world vector (3D).

- 1. Given a point (i,j) on the fisheye image (in normalised image coordinates), what is the vector (x,y,z) into the scene?
  r = sqrt(i^2 + j^2)
  phi = atan2(j,i)
  theta = r pi / 2
  x = sin(theta) cos(phi)
  y = sin(theta) sin(phi)
  z = cos(theta)

- 2. Given a point (x,y,z) in world coordinates what is the position (i,j) on the fisheye image?
  L = sqrt(x^2 + y^2 + z^2)
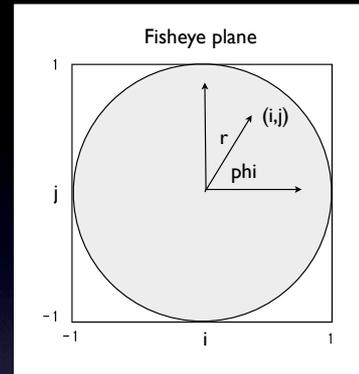 x' = x / L , y' = y / L , z' = z / L
  theta = atan2(sqrt(x'^2 + y'^2), z')
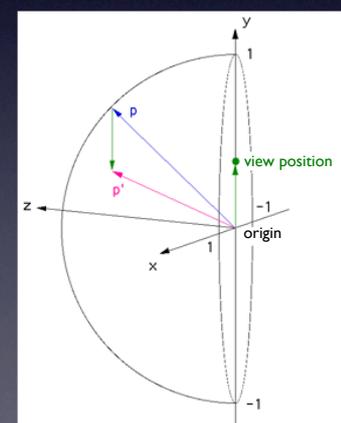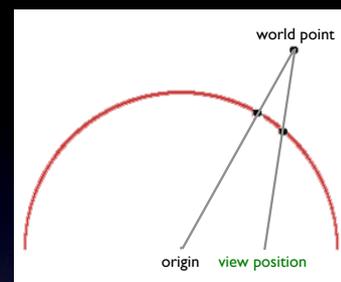 phi = atan2(y', x')
  r = theta / (pi / 2)
  i = r cos(phi)
  j = r sin(phi)

  Traditional to limit the fisheye image to a circle but it is defined outside the circle.

Offaxis fisheye projections

- The view of the imagery is only strictly correct (sweet spot) when the viewer is at the center of the hemisphere. Only at this position will straight lines look straight, for example.

- An offaxis fisheye allows this so called "sweet spot" to be positioned anywhere.

- Offaxis positions are generally applied to the plane parallel to the plane of the hemisphere rim but can also be applied to positions offset from the plane.

- Note that this is independent of the projection system. An analogous (but different) situation occurs when the projector is shifted away from the center of the dome. [See later].

- While some people apply a image warping to achieve a offaxis fisheye, this is not strictly correct. Moving the viewers position within the scene should result in parallax differences that are not supported by image warping.

- Very few rendering engines support offaxis fisheye projections.

- Can be particularly important for small domes and simulators where a correct undistorted view is important.

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. Very difficult to achieve this without a high quality seamless dome surface.
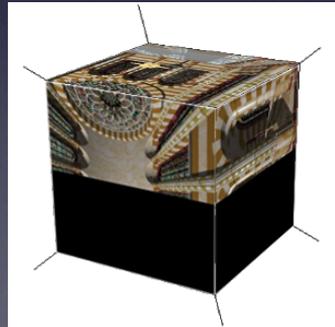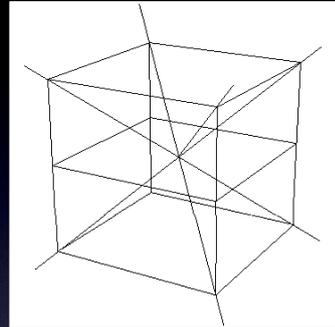
Rendering techniques

- Direct fisheye lens support, the most elegant minimal requirement. Be careful, an angular fisheye is not always what "fisheye" means in some software packages (an extreme wide angle lens).

- Render between 4 and 6 cubic maps and post processing to a fisheye projection. This is possible from any mathematical projection that contains the same (or greater) visual field as a fisheye projection. If the visual information exists then it can be resampled to create "any" projection with the same of small field of view.

- Spherical projection and post processing to fisheye, uncommon but interesting for some applications. [See later]

- Projector mapped rendering. Create cameras that match the projector configuration Sometimes proposed for multiple projector environments. Don't generally create a fisheye image at all and the result is only applicable for a particular site. Rarely used!
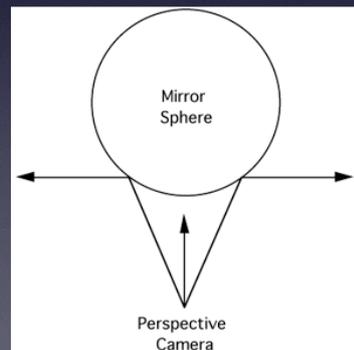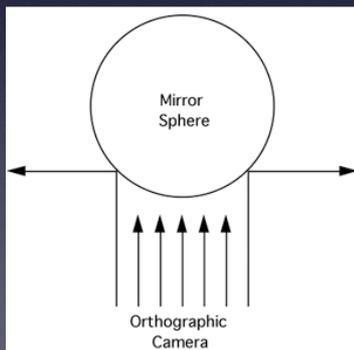
  [Will discuss some of the above further when talking about over rendering.]

Model used throughout this document is credited to Nathan O'Brien

- Rendering options continued ...

- Cubic maps. The fisheye is stitched together from the cubic maps as a post processing stage. Need to be attentive to antialiasing whenever resampling images.

- A very familiar concept in computer graphics, eg: creating HDR (high dynamic range) lighting environments, QuickTme VR, etc.

- The minimum is to render top face, and half of each of font, left, back, right faces. This is enough visual information to construct a fisheye image, namely, the visual field of one hemisphere.

- The main advantage is that all rendering engines support 90 degree perspective frustums. This is also one option for realtime.
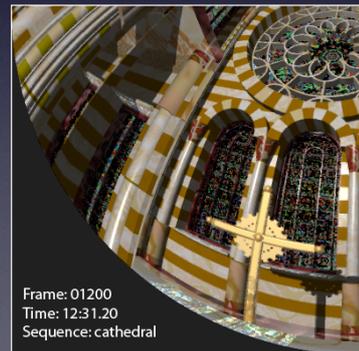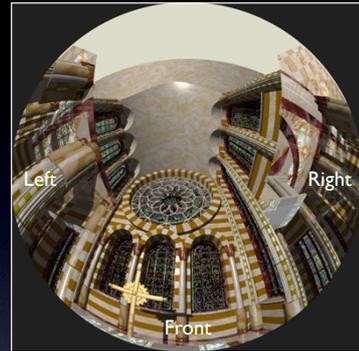

- Rendering options continued ...

- Can a reflective sphere be used to give a fisheye projection? For example, if the rendering program does not support a fisheye projection.

- 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 the mirror ... all sorts of things can cause problems.

- "Very close" but not strictly correct, I doubt many people can tell in a large planetarium due to the errors caused bu not being at the sweet spot. It is possible to post process the result such that the result is a true fisheye but that hardly worth the effort.
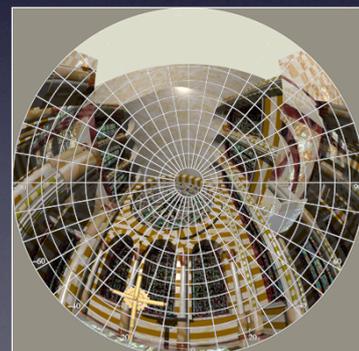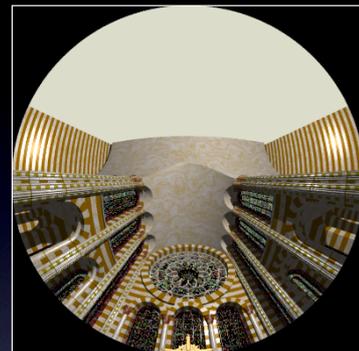
Fulldome movie formats - standards

- "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.

Left   Right
Front

Frame: 01200
Time: 12:31.20
Sequence: cathedral

Challenges for fulldome developers

- Need to model in detail much more of the scene than needs to be done for a "normal" limited field of view perspective projection.

- The requirement to render very large frame sizes compared to more traditional media. Perhaps the most common format for widely distributed content 3600x3600 pixel fisheye images is the standard. Compared to a XGA (1024x768) resolution animation that is 16 times the number of pixels per frame.

- Access to render farm with your rendering engine of choice.

- Lack of easy preview options. Small domes and projection systems are rare and relatively expensive, time in a digital planetarium is valuable for a number of reasons. [See later]

- Difficulty capturing live footage, so CG is the norm.

- Polar coordinate compositing, not necessarily available in your favourite compositing software.

- Realtime/interactive applications are lagging behind. Given capabilities of todays graphics cards there is now no excuse.

Break

Projection technologies

- At one level (ideally) the content developer need not worry about the projection details,.

- In reality one needs to be concerned with all sorts of issues in order to maximise the quality content in a particular projection environment and dome installation.
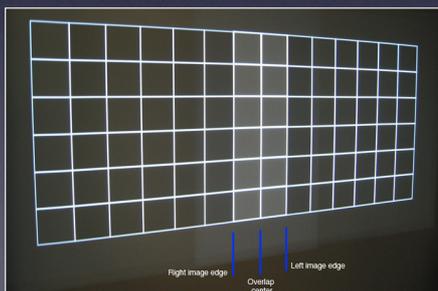
  Broad categories:

- Multiple projectors: more than 2 projectors that tile the dome and the individual images pieces are edge blended together to form a continuous image on the dome. Generally 5, 6, or 7 projectors located around the rim of the dome but there is no standard configuration due to differences in the existing builds, presence of central star projectors, projector optics.

- Single or dual projectors with a fisheye lens.
  Used to be the main arrangement for small domes and portable systems.
  Now starting to be installed in large planetariums due to projector resolution improvements.
  Many believe this will be the most common technology in the near future, certainly it is the simplest arrangement that solves many issues with multiple projector systems.

- Single projector and spherical mirror. Relatively new option, first installed in 2004. Largely the domain of small domes and portable systems where it offers some advantages, besides the relatively low cost.

- Laser, one of the newer techniques.
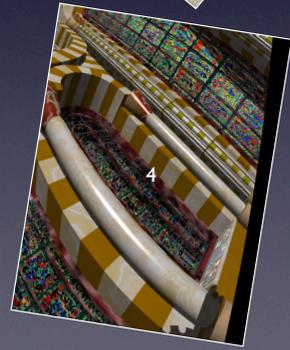 Delivers very bright high dynamic range images and excellent black.
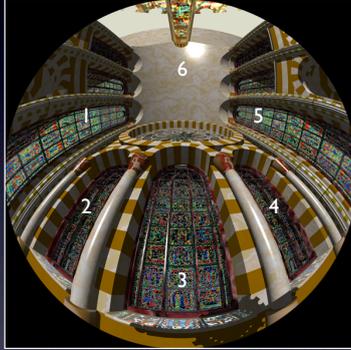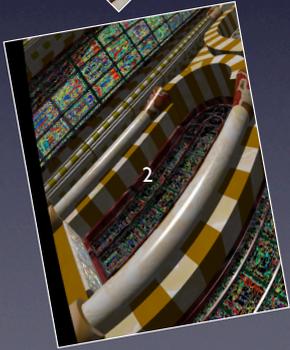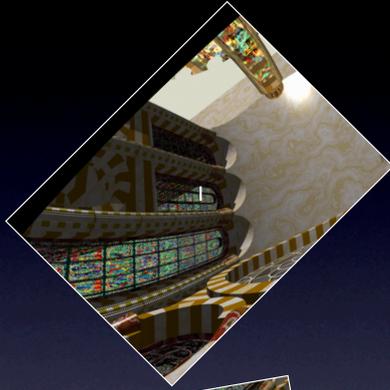
Multiple (>2) projectors

- Fisheye gets sliced up and optionally warped into N pieces, N = number of projectors employed. The exact geometry depends on the installation, almost no 2 are alike so slicing is usually performed on site with local configuration files.

- Traditionally regarded as the highest resolution option.

- Generally have the highest installation cost and cost of ownership.

- The projectors are typically around the rim of the dome and thus don't impact on seating.

- Edge blending is applied across the image overlap region. Simplistically at any point in the overlap the mask value multiplied by the colour value of one image + the mask value multiplied by the colour value of the second image = the intended colour. Note: need to add luminance the RGB values so correction for projector gamma is required.

- A number of edge blending technologies, most common are software blending, hardware blending (acts on video signal), or physical masks are also sometimes used.

- 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.
  - Colour variation depending on how much use a projector gets.
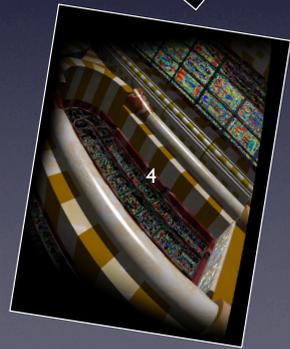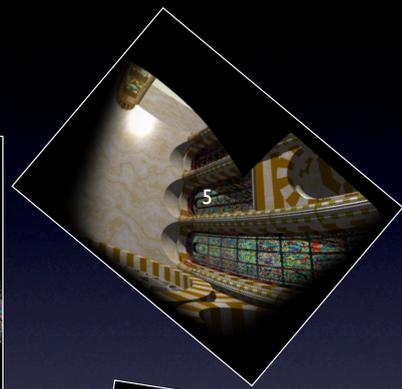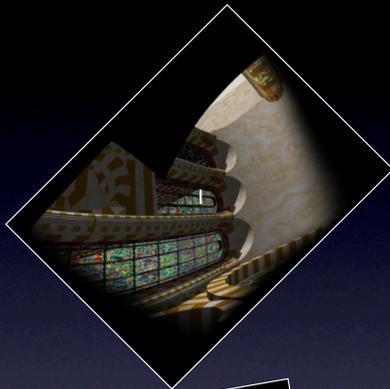

- Multiple projectors continued....

- Historically since black was important in planetariums it was necessary to use projection technologies that allowed very good blacks, namely CRT projectors. For example, if true black isn't achieved across an edge blend of intended black imagery the two greys will add to form a lighter grey. [You can't subtract light].

- Poor edge blending is most noticeable on blacks and regions of constant colour or slow colour gradients.

- DLP and other black enhanced version of LCD projectors are starting to be used.

- Very difficult, if not impossible, to get a perfect edge blend across all colours and brightness levels.

- Interesting attempts at automatic camera based alignment rather than the usual manual (technician based) alignment.

Right image edge   Left image edge
Overlap center
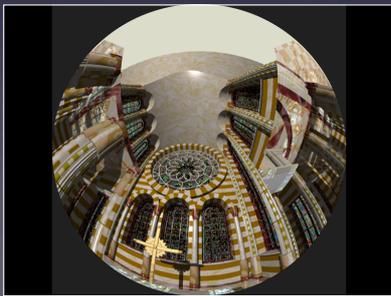
- Slice/warped examples for a **6** projector dome.

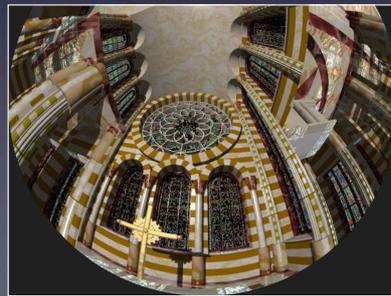- Slice/warped examples for a **6** projector dome with edge blending.

Fisheye lens projection

- Single or dual projectors and fisheye lens is the simplest most natural way to project fisheye images within a hemispherical dome.

- Has been very popular for small dome based simulators.

- Inscribed fisheye only uses 59% of the pixels, truncated option uses 84% of the pixels. For planetarium style configurations the truncation is usually at the back. For upright domes it is usually at the floor.

- Hard not to have chromatic distortion near the rim, extreme angles through the fisheye lens. Quite a bit of light can be "lost" through the lens.

- Most full fisheye projection system use SXGA+ and 4:3 (no significant advantage with HD since the inscribed circle is limited to the image height, 1050 vs 1080).

Inscribed fisheye in a 4:3 frame

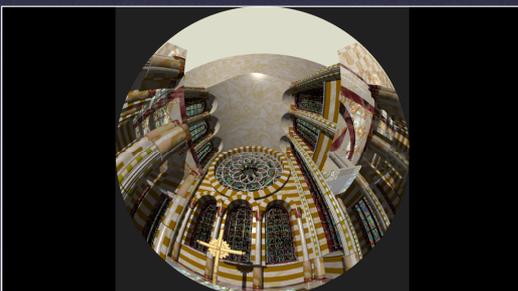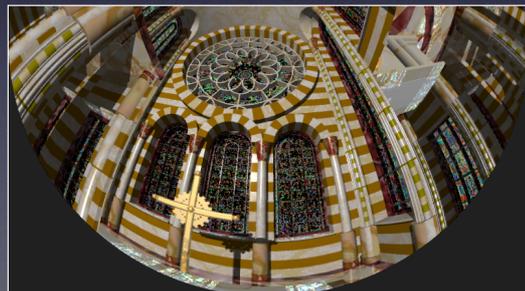Back truncated fisheye

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- Fisheye lens projection continued.....

- Full fisheye in 16:9 aspect ratio projector only uses 44% of the pixels.

- Truncated 16:9 uses 80% of the pixels.

- Dual projectors suited to 16:9 aspect ratio projectors.

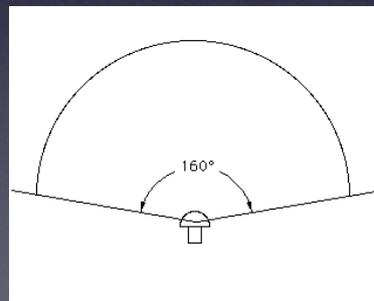- Highest resolution single projector is from Sony at 4096x2160 (essentially 2:1).
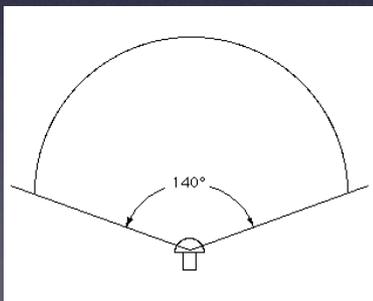

Inscribed fisheye in a 16:9 frame
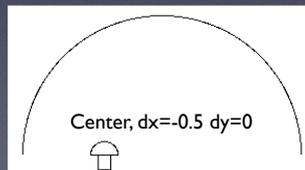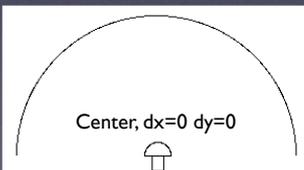

Twin fisheye pairs in a 16:9 frame

- Fisheye lens projection continued.....

- Can be issues of positioning the projection hardware in the center where the best seating position (may) be.

- One doesn't necessarily need a 180 degree fisheye lens, 160 degree is more common, it just means the lens is below the spring line of the dome.

- The content is still a 180 degree fisheye, the projectors job is still to fill the hemisphere with a 180 degree field of view.

- However this is not the case for content designed for an audience whose head hight is well below the spring line, in that case the fisheye may indeed be less than 180 degrees.

Offaxis fisheye for off-center projector

- Often desirable to position a fisheye projector away from the center of the dome, for example so that the viewer can reside at the center of the hemisphere.

- Correction for this distortion can be compensated for by an image warping, postprocessing.

- Not terribly common for planetariums where no single sweet spot is necessarily available, becomes more important as the dome size decreases, and very important for single person domes if an undistorted view is desired.

Center, dx=0 dy=0   Center, dx=-0.5 dy=0   Center, dx=-0.5 dy=0.5

Fulldome projection using a spherical mirror

- A single projector and a spherical mirror can scatter light across a wide field of view.

- Presenters "invention" so please excuse any bias I might have.

- The images employed are still fisheye projections but they are warped such the result is correct on the dome surface. Different warping is required depending on the exact geometry of the projection system and dome.

- Warping is straightforward to perform in real time presenting minimal performance overhead.

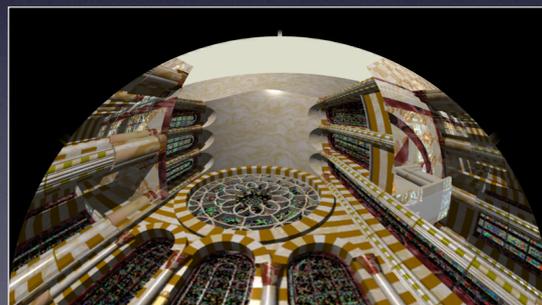- Main issue is getting a uniform focus across the dome, good results requires good projector optics and depth of focus.

- Spherical mirror projection continued ....

- 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.

Typical planetarium warp (4:3)

Example for an upright dome

- Spherical mirror projection continued ....

- Hardware setup is very straightforward.

- Suited to smaller domes because the hardware occupies space on the edge of the dome, similarly for upright domes. [Can leave further discussion of this to demonstration after lunch].

- A recent innovation is a folded light path by using another plane mirror, this even further reduces the impact of the hardware within a small dome.

- Adoption and software support by existing planetarium applications is increasing. The issues being
  - the extra hoop to jump through to to the warping.
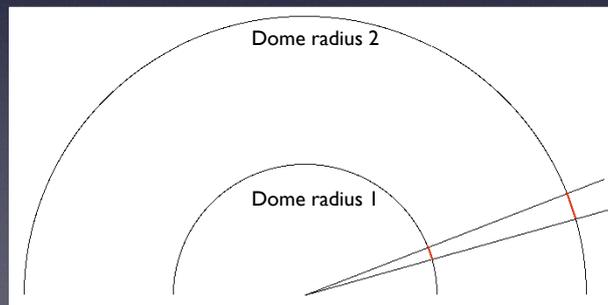 - how to derive the correct warping mesh.

Variations between installations

- 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

- 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.

- Resolution continued ....

- Cannot necessarily create high definition 4K fisheye images and expect to be able to down sample 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?
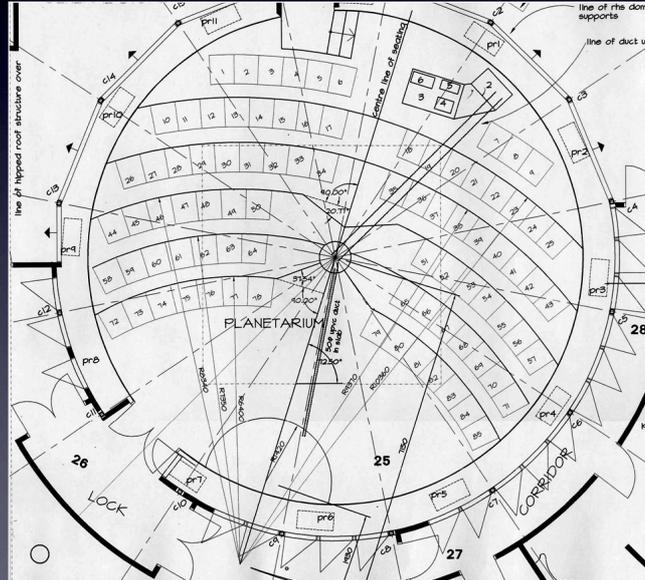
Contrast, gamma, reflectivity, colour space ...

- 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 a dome when the surface becomes invisible.
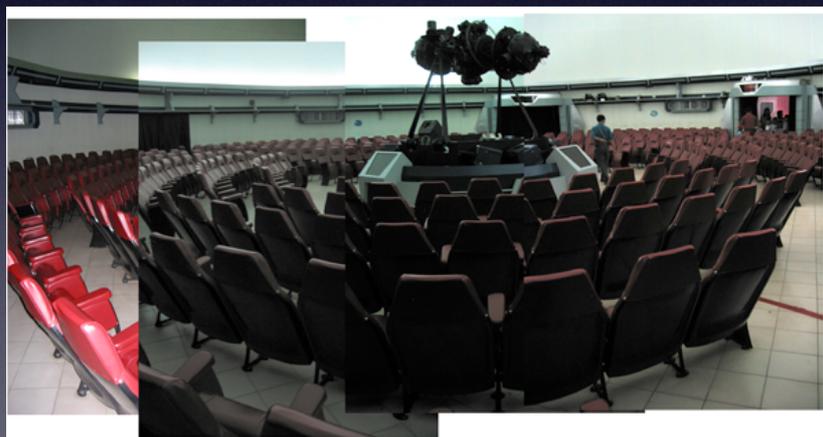

- Colour space refers to the colours that can be represented given a particular projection environment/technology. This also applies to image generation and capture.

- 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.

Seating arrangements

- Uni-directional seating vs omni-directional.

- New planetariums tend to have uni-directional seating as do small domes.
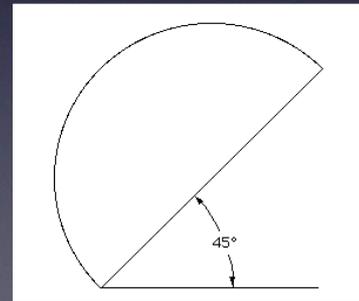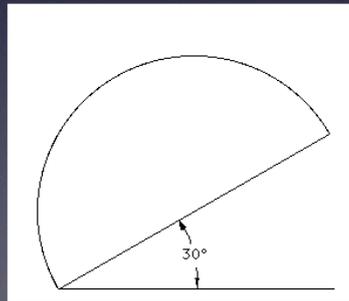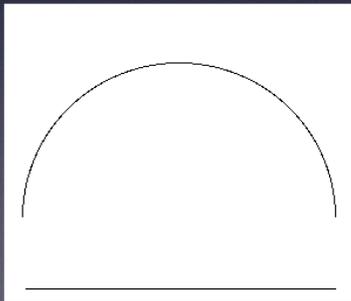

- Seating arrangements continued …

- Omni-directional seating, more prevalent in the older planetariums where the seats surround the central star projector.

- For digital content it is quite challenging to think about how one creates "interesting" action/story over the entire dome surface so that everyone gets a satisfactory experience irrespective of what section of the dome they are looking at.

Coping with different dome and seat angles

- This primarily concerns where in a directionally seated dome is the center of attention. Combination of dome tilt and seat angle. Fisheye is rotated to cope with this.

- 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 is a strong negative cue.

- Directed "forward" motion cues also implies a horizon, this includes forward motion as well as horizontal panning of the camera.

- The solution of course is to tilt the fisheye camera such the horizon appears correct. But how does one then have a single version of the movie that can be used in multiple installations each with a potentially different dome tilt?
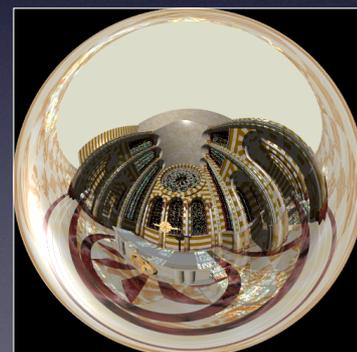

- Dome and seating angle continued ...

- "Over render" the fisheye.

- Fisheye projection can have more than a 180 degree aperture.

- Render with a wider aperture and then in post production a 180 degree fisheye at various angles can be generated. Common angle 220 degrees, can't go too wide for resolution reasons.

- Need to render the fisheye at higher resolutions in order to get the desired resolution for the 180 degree fisheye.

- The key with this and other possible techniques is that if the required visual field is captured then arbitrary projections can be created. A recurring theme.
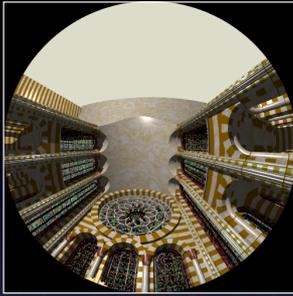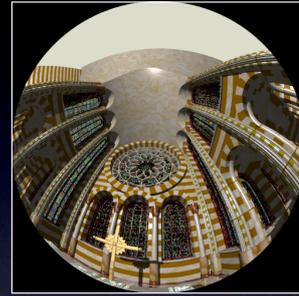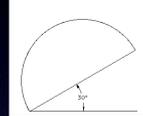

| 180 degree fisheye | 220 degree fisheye | 360 degree fisheye |

- Dome and seat angle continued ...

- Examples: Fisheye tilt to compensate for dome angles.

Traditional planetarium

30 degree tilt: OmniMax

45 degree tilt

90 degree tilt: upright dome

- Dome and seat angle continued ...

- Render 5 or all 6 fully rendered cubic maps rather than the minimum as discussed earlier. From these any dome orientation can be derived.

- See "cube2dome", my stitching software. Also "Glom" and others.

- Need to pay careful attention to antialiasing to avoid sampling issues and edge effects.

- Resistance to this from content developers usually because rendering resources are already stretched.

Dome types

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

- Inflated are usually small/casual setups that usually preclude the use of multiple projectors.

- Very difficult to get a seamless surface, surface is therefore usually visible to some extent limiting immersion.

5m

30m

- Dome types continued ...

- Hard shell domes, popular at trade shows and content preview environments.

- Rarely larger than 6m in diameter, often disassemble for practical transport and installation requirements.

- Most common for small professional domes.

- Usually have interesting acoustic properties, just as light bounces around a dome, sound does also and focuses along the axis of the hemisphere from about 1/3 the radius about the center.

- Dome types continued ...

- Typical planetarium dome is a fixed solid structure constructed from steel.

- Traditional planetariums will have a star projector in the center, hopefully below the spring line for clear line of site for digital projection systems.

- Large fixed domes usually employ perforated surface to control gain, acoustics (speakers behind the dome), and air flow.

- Dome types continued ...

- Plane faced domes have a harder time creating an immersive experience because the dome surface is in general always visible.

- Usually based upon bucky balls or geodesic geometry, often intentionally chosen for their mathematical "elegance".

- Easiest domes to build, most common in the amateur community.

- Generally solid so also can have "interesting" acoustic properties.

3m	20m

Other considerations

- 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.

Live action capture

- Capture of high resolution fisheye stills using a good digital camera and fisheye lens is relatively straightforward.

- For video the key issue is getting sufficient resolution.

- 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 are often still OK for small domes or directional seating. Tilting also possible for partial fisheye video.

- Issues of lens quality, chromatic error and focus issues on the rim.

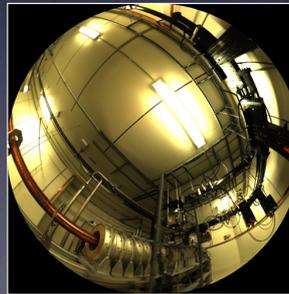Canon HV20 HD 1080p

Partial fisheye

- Live action capture continued ....

- 360 degree capture. Example: Ladybug camera.

- 360 panoramic cameras rarely capture sufficient vertical field of view, some do, see Roundshot cameras with fisheye lens.

- Perhaps the most cost effective and smallest multiple camera unit.

- 360 degrees by 150 degrees, LadyBug 1 was 15fps, LadyBug 2 is 30fps.

- Native resolution of spherical projections is 3600 x 1800. Ideally suited to spherical map movies for navigable movies. Can be used to create fisheye projections over a wide range of fisheye orientations.

Spherical projection (single frame)

One possible derived fisheye

Micoy

- Live action capture continued ....

- Custom rigs consisting of multiple cameras, required in order to sufficient resolution for usage in large planetarium.

- Can be issues stitching since the focal point of the cameras are not at the same location. This leads to parallax errors making stitching difficult.

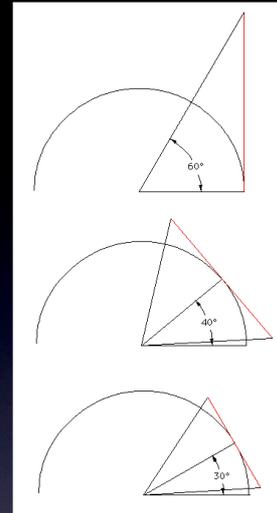- Serious issues with portability, most have associated hard drives and mains power requirements.

iCinema

iCinema

- Live action capture continued ....

- It is of course possible to capture standard perspective frustum footage and add that as part of a fisheye image. Standard camera field of view is a surprisingly a small part of a fisheye.

- Lots of possible strategies depending on the footage and style of the content.
  - footage can be bound within a plane or device (eg: television) in an otherwise CG frame.
  - footage can be (slightly) warped to fill in more of the fisheye space.
  - footage can be projected into fisheye space so as to give an undistorted view.

- Subsequent tricks to integrate this content during compositing.
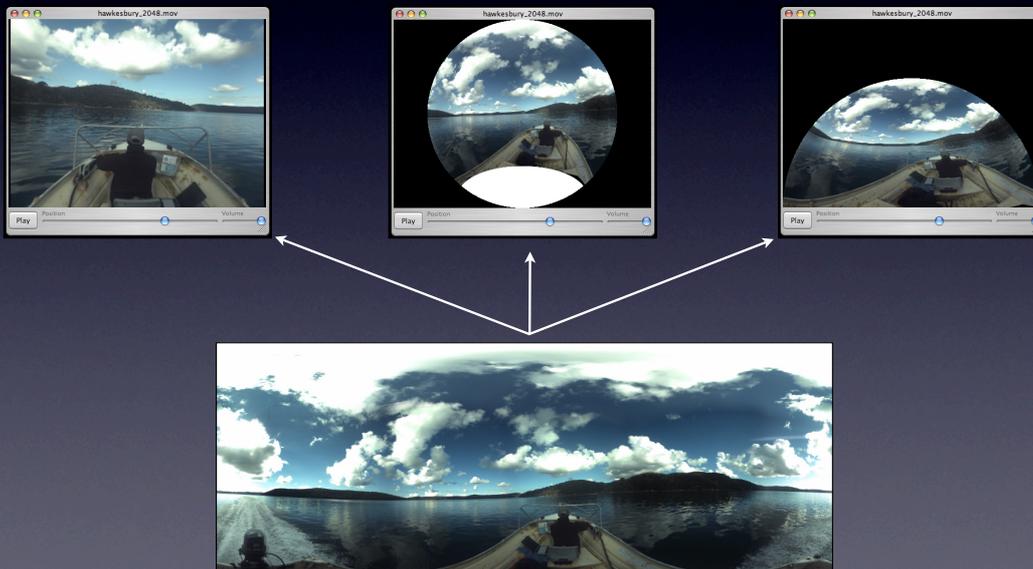

Example: 80 degree FOV perspective

Realtime applications

- Realtime APIs such as OpenGL and Direct3D do not support fisheye projections.

- One approach is to mimic the cubic map technique by rendering in multiple passes to textures before finally applying the textures to a mesh with texture coordinates such that a fisheye projection results. All rendering APIs support 90 degree perspective projections.

- Another approach is to use vertex shaders to distort the geometry is just the right way that when then viewed with an orthographic camera the result is a fisheye projection. Note: a line between two points in a fisheye projection is not a "straight line". The consequence of this is that lines and planes need to be tessellated before being sent to the graphics card, the most efficient algorithm to do this is not obvious.

- These have their own relative merits. The main issue with the vertex shader is the algorithm that tessellates the polygons, when do they need to be tessellated and by how much. As a generalisation, the vertex shader approach is ideal for points/lines and simple geometry, the cubic maps are often better for highly textured scenes made up of primarily polygons.

- Realtime applications continued ....

- Most planetarium suppliers have interactive applications for visualising astronomy data from the scale of planets up to the larger scales in the Universe.

- Packages from the major suppliers:
  - Digistar from Evans and Sutherland
  - Digital Sky from SkySkan
  - StarryNight from Spitz
  - Virtuarium from GOTO
  - UniView

- While claims are sometimes made regarding their generality, they don't in general met the diverse needs of many/most other disciplines, they all originally were developed for astronomy content.

- Perhaps the most popular small dome package with fisheye support is Stellarium (Open Source).

- There are a number of realtime applications that meet specific needs. If you have the source code for a 3D application then it is relatively straightforward to add fulldome support. The main issues involves performance, if your application is already struggling to meet the desired frame rates then it will most likely be problematic moving to a fisheye version.

- Elumenati have a free API, for both DirectX and OpenGL.
  Some are using tools such as VirTools.

- Realtime applications continued ....

- There is also a middle ground, content that is basically image based but one can enjoy limited interaction. Simplest example of this is QuickTime VR, equivalents exist that render to fisheye. There are also navigable movies where the single image in QuickTime is replaced by a movie, as the movie plays one can interactively change the view direction. [Demonstrations of this in the dome].

- Realtime applications continued ....

- Exciting applications for gaming, and the use of game engines to support virtual reality applications.

- Some engines (such as Unity and Quest3D) have a powerful enough scripting language to create the fisheye (approximation using a spherical reflective sphere).

- Other game engines have source code options for developers.

- There is good reason to believe that peripheral vision gives players a gaming advantage, at least for games based within a 3D world. This reflects the evolutionary advantage of peripheral vision: to detect predators as early as possible.

Halflife

Quest3D

Closing remarks and online resources

- Forums
  - yahoo group: fulldome
  - yahoo group: small_planetarium
  - yahoo group: DomePro

- DomeFest - International (juried) fulldome festival (http://www.domefest.com/)

- Immersive Cinema Workshops (http://fulldome.multimeios.pt/)

- International Planetarium Society (http://www.ips-planetarium.org/)

  After lunch (not a formal part of the course)

- Informal discussion on any topic relating to fulldome.

- Demonstration of local upright dome.

  Sunday evening

- Experience the fulldome showreel and Best of DomeFest at the "Horizon - The Planetarium" on Sunday evening at 7pm.

No fulldome talk would be complete without photos of star projectors.
These devices were the first high quality projection systems in planetariums and still
give higher quality star fields than almost all digital systems.