iDome
Most of what you need to know

Paul Bourke

iVEC @UWA

Contents

- History and motivation: immersion.
- Technologies: fisheye lens, spherical mirror.
  - Warping and calibration.
- Principles: fisheye and spherical projections.
- Content creation
  - Photography
  - Filming: fisheye and 360 video
  - Rendering, CG
  - Realtime: vertex shader, cube maps
- Key software: Quartz Composer, warpplayer, meshmapper, Unity3D.
- General guidelines.
- Further reading.

- These notes will online.

History

- Dome originally built by iCinema for exhibition called “glasshouse” at the Powerhouse museum. Used a projector and fisheye lens.
- 2003: Paul Bourke develops spherical mirror projection.
- Fisheye lens system replaced by spherical mirror. Volker Kuchelmeister at iCinema suggests an alternative placement of projector behind the base of the iDome.
- 2005: Used as truck driving simulator at Centre for Mining at UNSW.
- 2007: iDome installed at iVEC@UWA.
- 2007: Treehuggers.

History

- 2009: iDome installed at Science Centre University of Wollongong in conjunction with ARC Centre of Excellence for Electromaterials Science
- 2010: Remote operations Rio Tinto.
- 2012: running room.

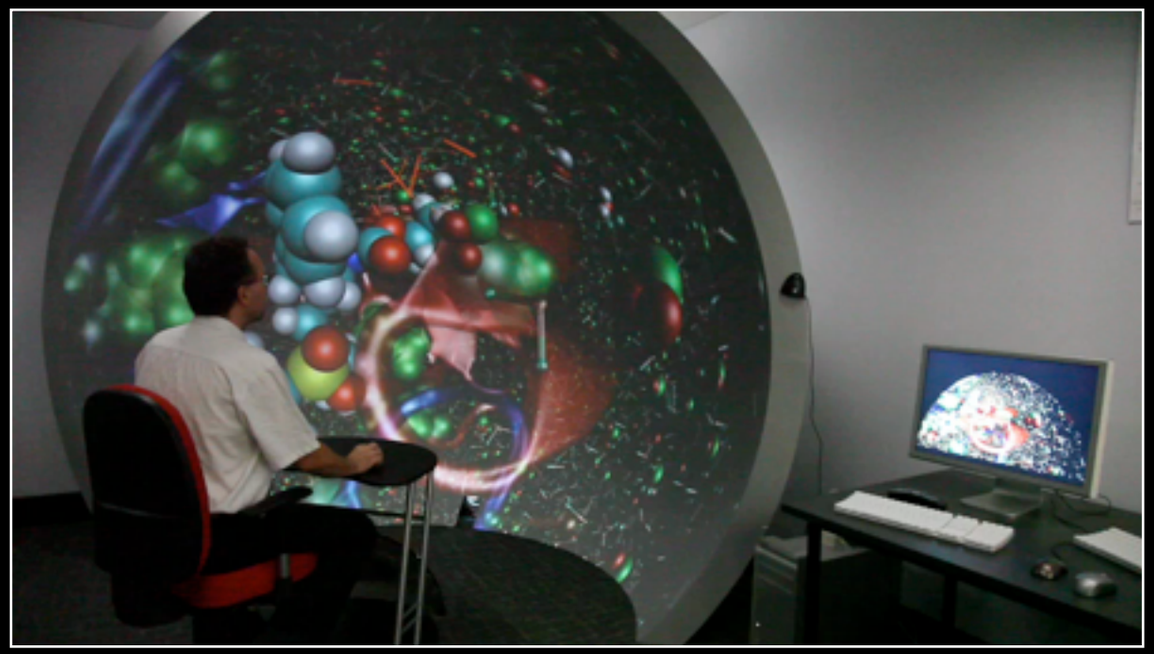
Motivation

- Visualisation largely about conveying information to the brain through our sense of sight.
- Might as well leverage the characteristics of our visual system.
- Stereopsis - visual fidelity - peripheral vision.
- Peripheral vision attributed to our sense of “being there”, “presence”.
- Evolutionary reasons for peripheral vision, detecting predators in our far visual field.
- Easy to imagine that this could also be an advantage in game play.
  Interesting to note that gaming has partially adopted stereopsis which I claim has little game play advantage and lots of disadvantages.
- Sense of depth from motion cues. [Molecular example]

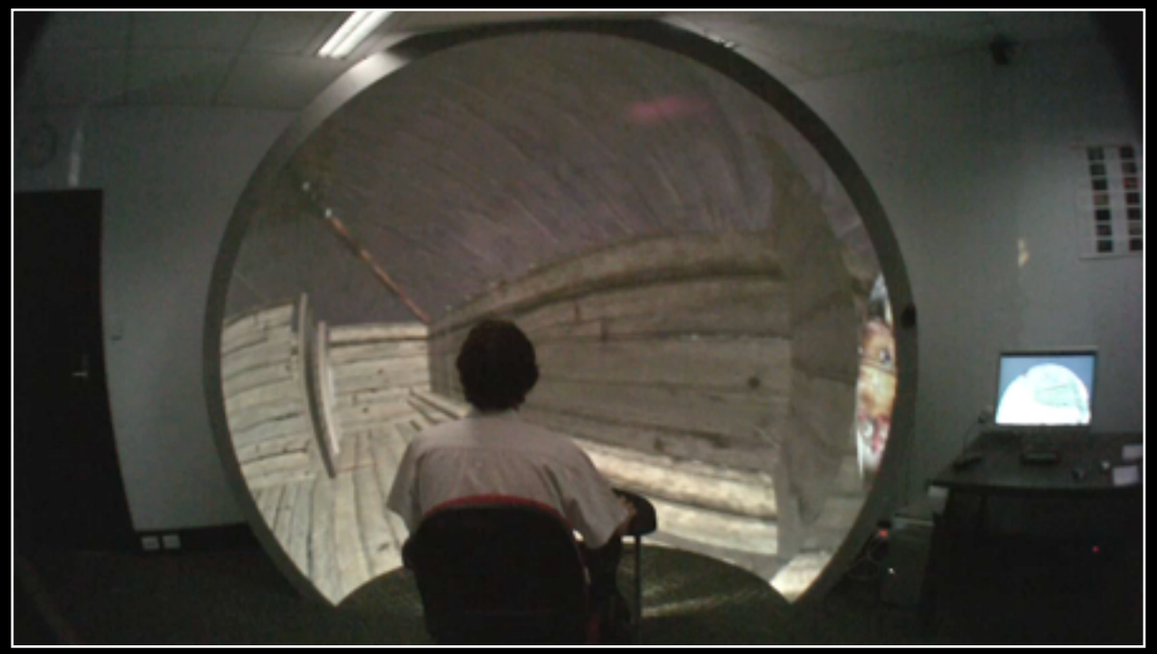
Application examples

Science education

Remote operations (mining)



Science visualisation



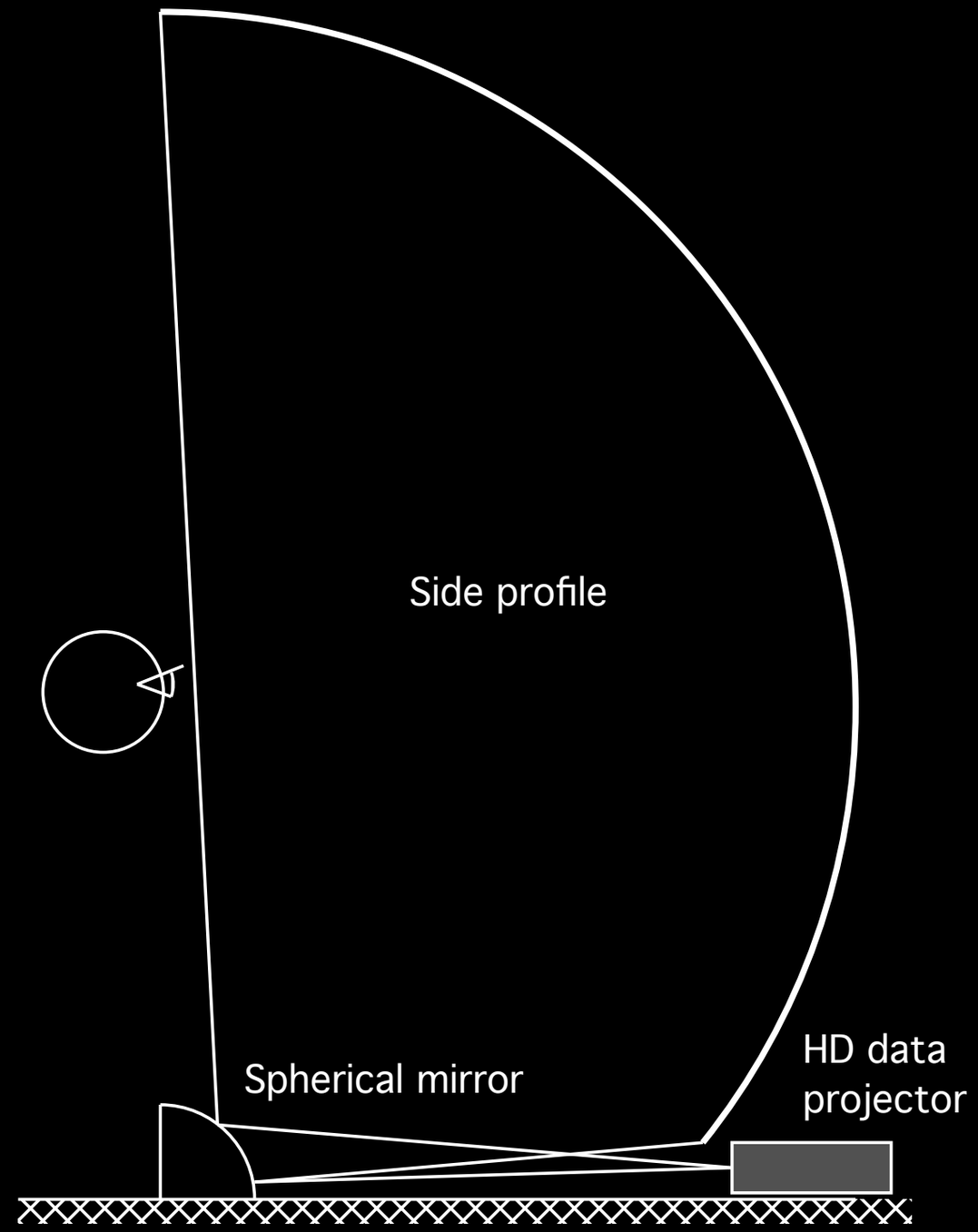
Virtual heritage

Technology: Fisheye vs spherical mirror

- Earlier small dome system was the VisionStation.
- Projector needs to be in (or close to) the center of the dome, the ideal location for the viewer.
- Good quality fisheye lenses are expensive.
- Doesn't benefit from current trent towards 16:9 aspect ratios, works better with square aspect.
- Quality of well designed spherical mirror system matches that of most single projector fisheye systems.

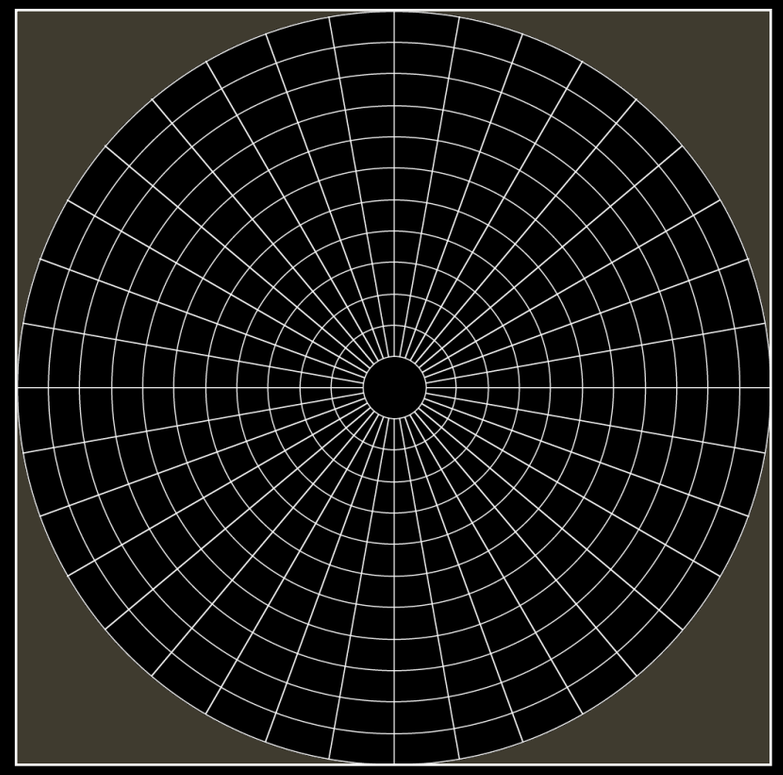
Technology: fisheye vs spherical mirror

- Purpose of the fisheye lens and spherical mirror is to spread light across the dome.
- In the case of the spherical mirror an image warping is required to correct the distortion introduced.
- Main advantage of the spherical mirror approach is it largely hides the projection system.
- Another advantage is it decouples the optics from the projector, making it possible to replace/upgrade the projector independently.
- Main disadvantage is the extra complexity arising from the warping.
- Nothing special about 3m except fits in standard height room. Degree of truncation has historical significance only.

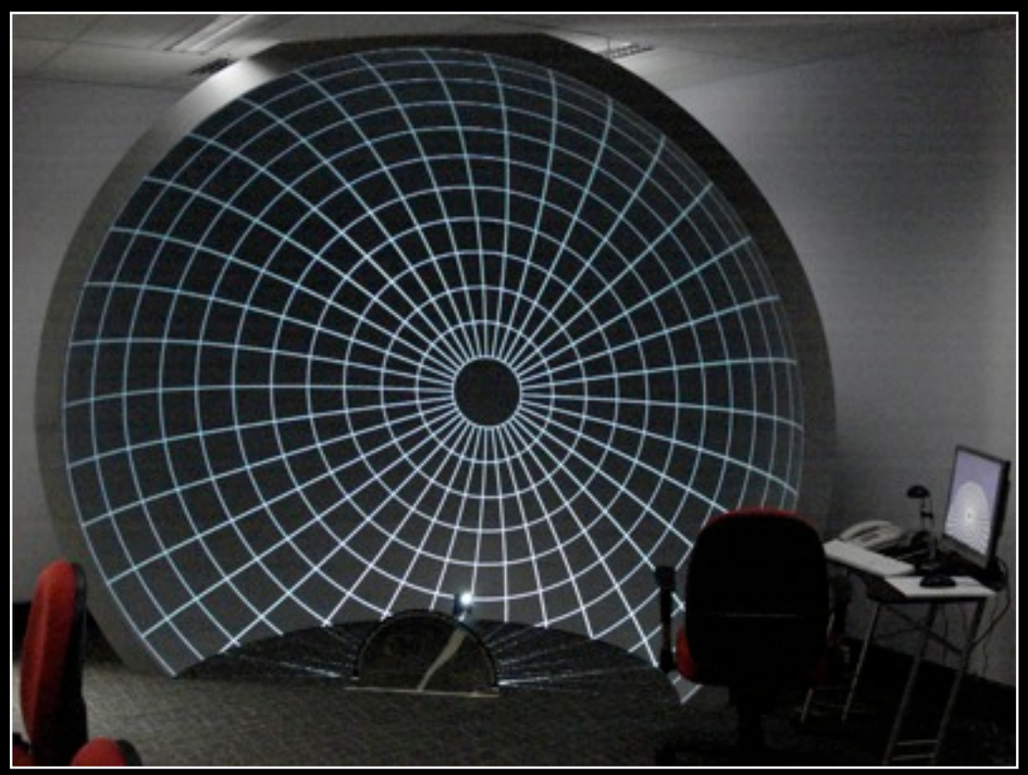


Fisheye warping

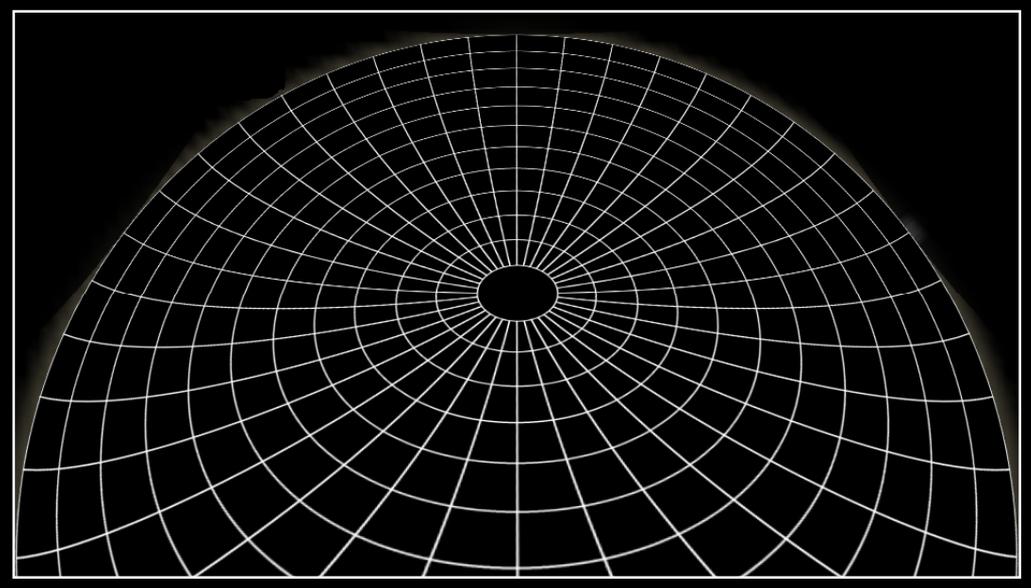
- Usual calibration image are lies of latitude and longitude.
- The lines of longitude should be straight.
- The lines of latitude should be circular rings.
- Illustrate on Dome



Fisheye polar grid



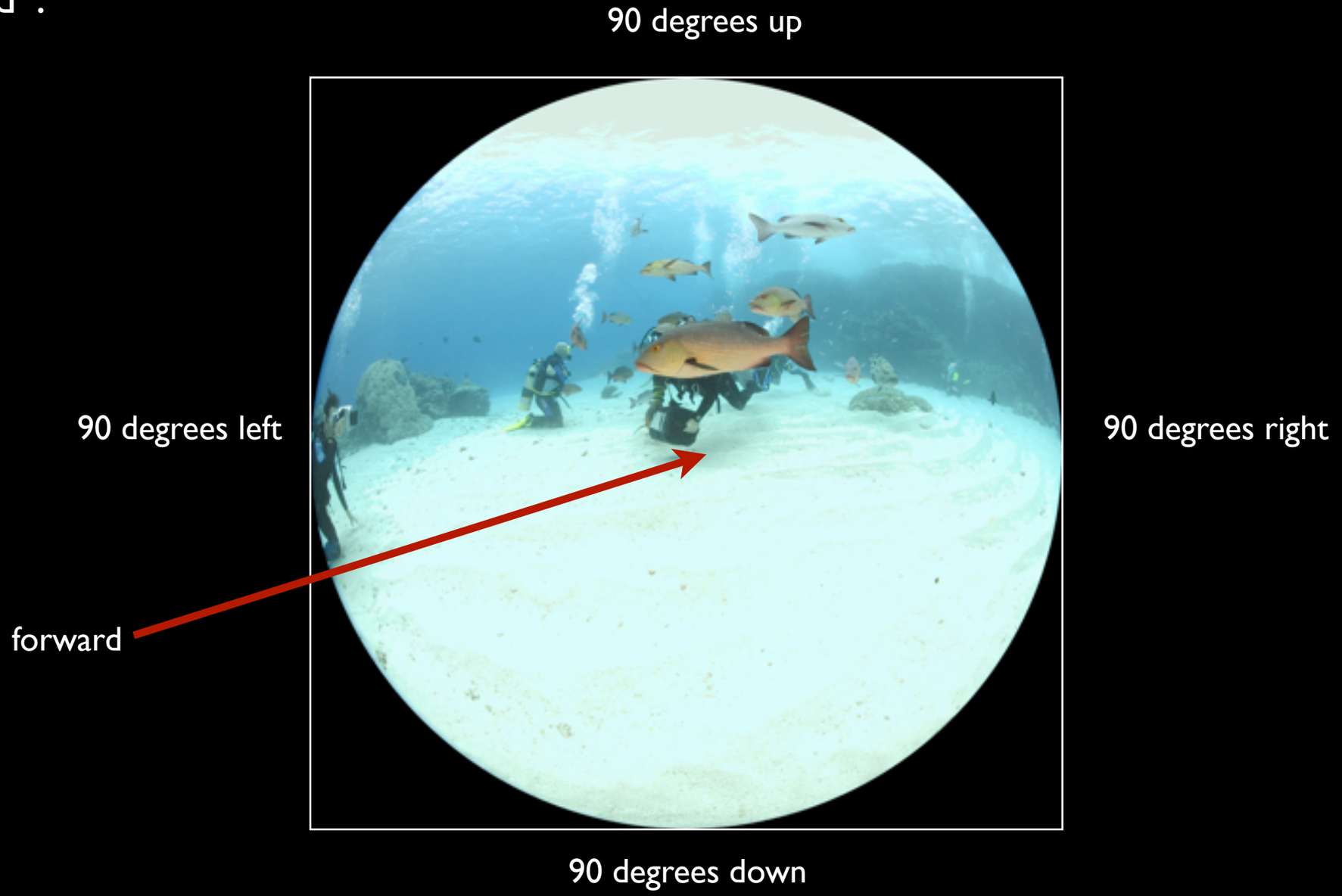
Result in iDome



Warped fisheye

Anatomy of a fisheye projection

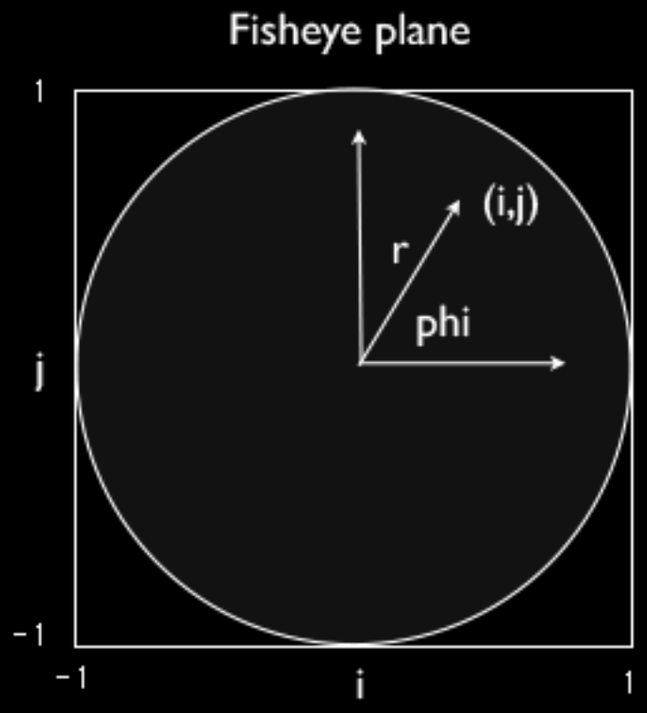
- Standard perspective projections are (obviously) unsuitable for dome projection. They do not capture the field of view required.
- Simplest is a fisheye projection.
- Captures “half the world”.



Anatomy of a fisheye projection

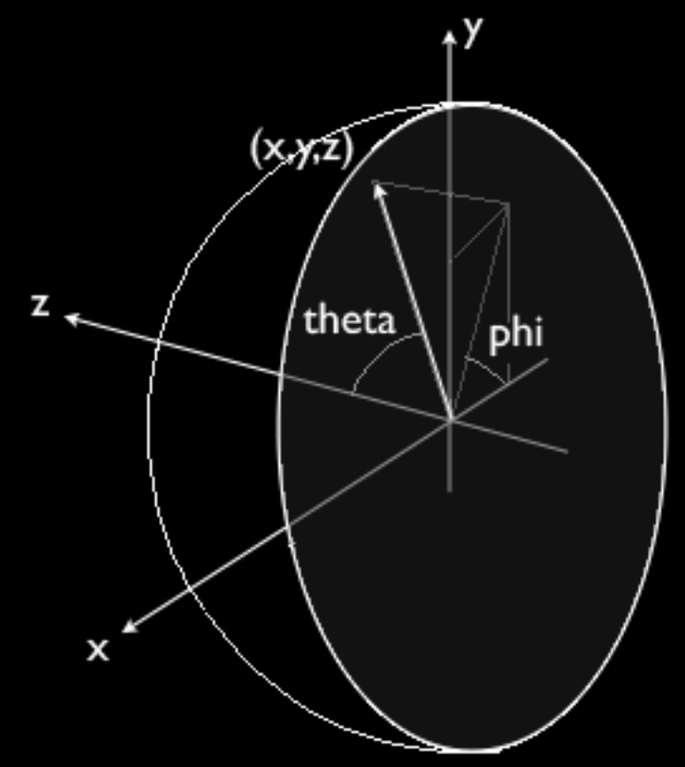
- Typically need to relate the mapping to/from fisheye image coordinates (2D) to a world vector (3D).

- 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)



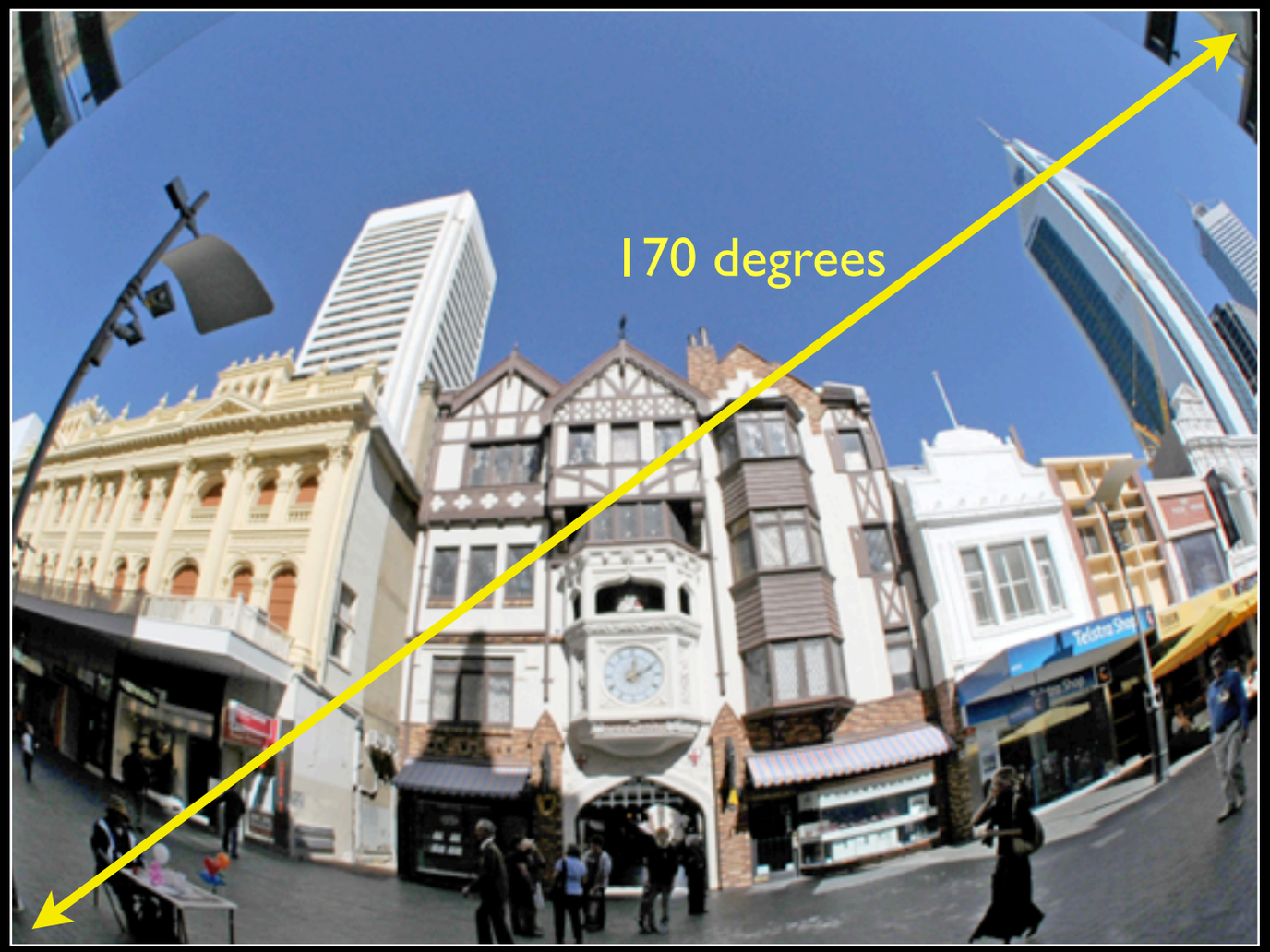
- 2. Given a point (x,y,z) in world coordinates what is the position (i,j) on the fisheye image?
  L = sqrt(x^2 + y^2 + z^2)
  x' = x / L , y' = y / L , z' = z / L
  theta = atan2(sqrt(x'^2 + y'^2), z')
  phi = atan2(y', x')
  r = theta / (pi / 2)
  i = r cos(phi)
  j = r sin(phi)

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



Content creation: Photography

- There is a distinction between “wide angle fisheye” and circular fisheye.
- We typically use a Canon 5D and Canon 8-15mm fisheye lens.
- [Show examples]



170 degree wide angle fisheye

Circular fisheye

Content creation: Video

- More difficult to achieve sufficient resolution. HD camera (1920x1080) and a fisheye circle that fills the sensor only gives a 1080 pixel fisheye.
- Red Scarlet gives a 2K high fisheye.

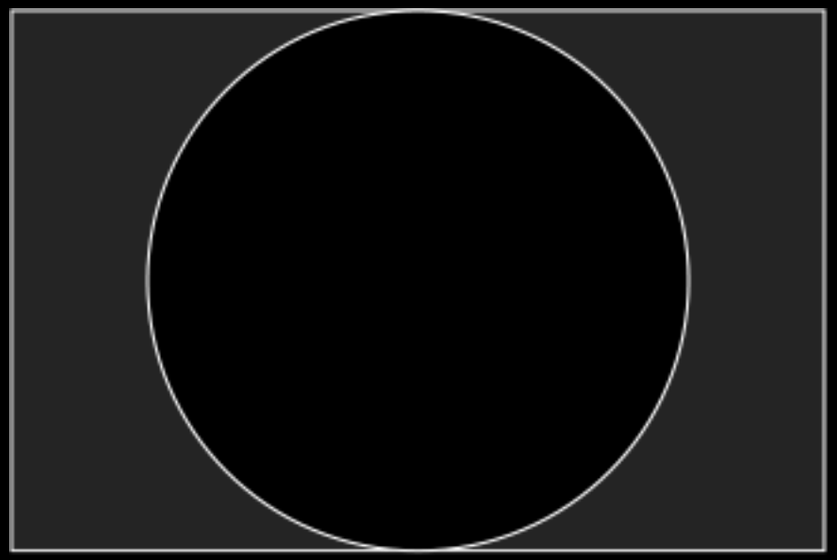
Canon HV20 HD 1080p

Red Scarlet

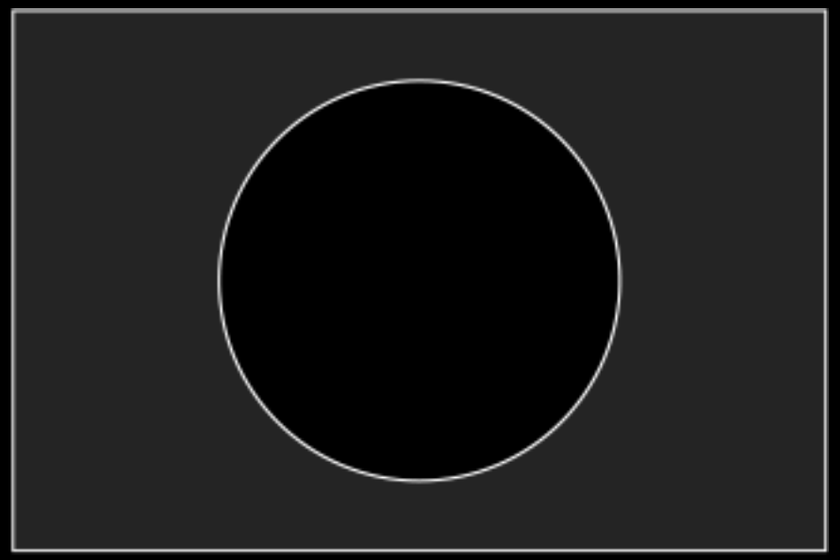
Content creation: Sensor and fisheye circle

- When sourcing fisheye lens for a particular sensor pay attention to the sensor size and fisheye circle.
- If the fisheye circle is smaller than the sensor then full resolution is not achieved.
- If the fisheye circle is too large it will be truncated.
- Truncation at the bottom is not an issue for the iDome.

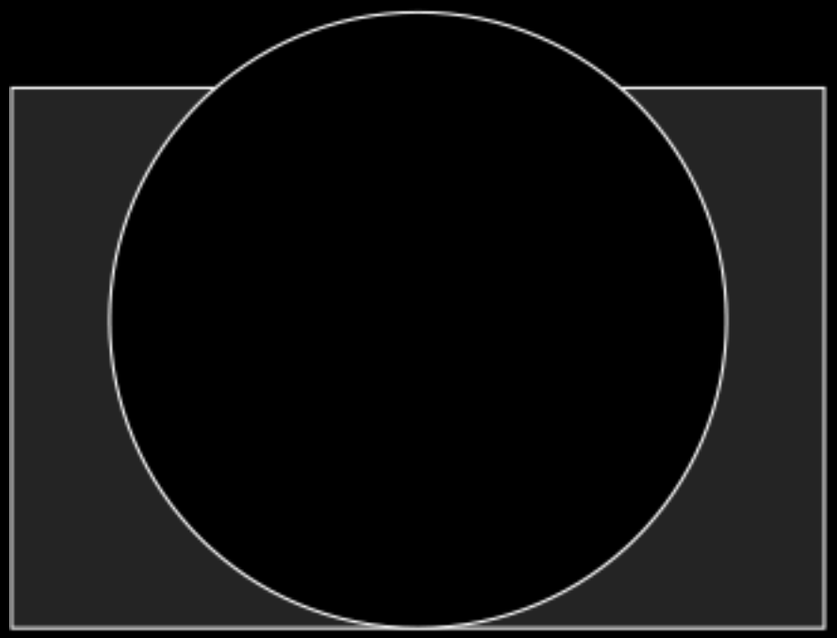
Content creation: Sensor and fisheye circle



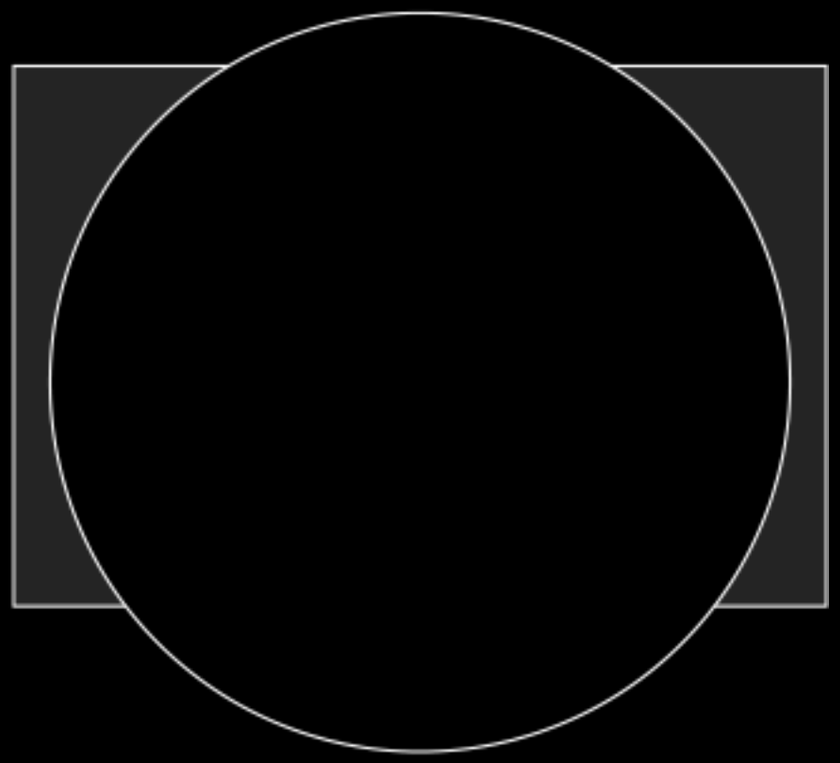
Ideal, full sensor utilisation.



Full fisheye but inefficient use of sensor.



Truncated fisheye
May be OK for some planetariums,
or the iDome if truncated at the bottom.



Fisheye truncated to and bottom.

Content creation: Spherical projections

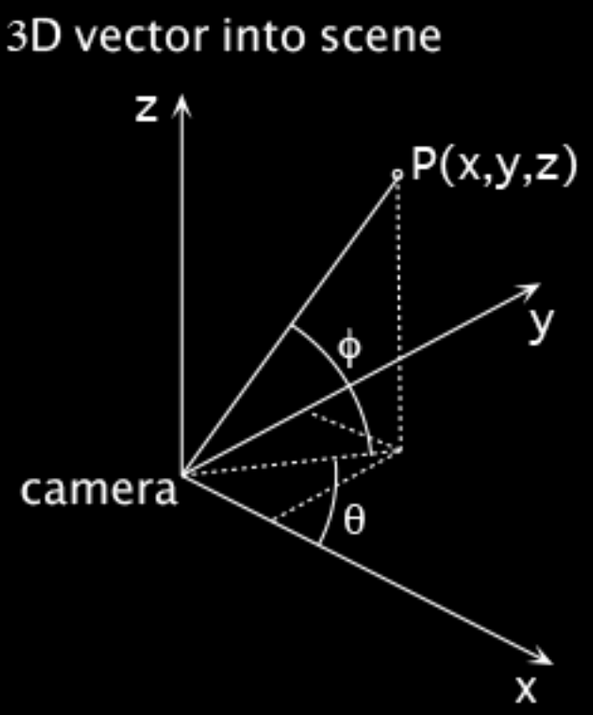
- A spherical projection captures the whole environment.
- This allows for navigation within the iDome.
- [Show examples]

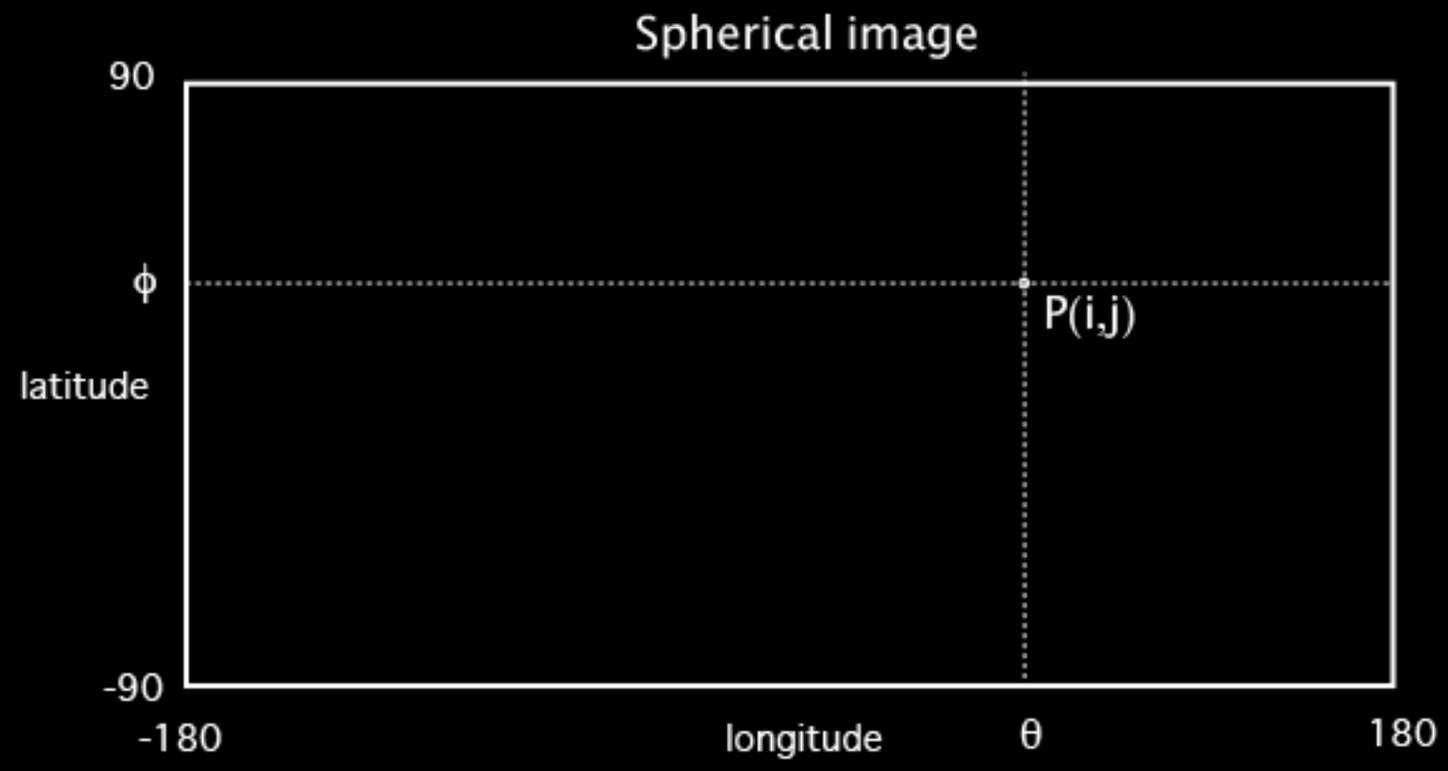
Anatomy of a spherical projection

- Contains sufficient visual information for a presentation into a hemisphere, actually captures more than required.

- 1. Given P(i,j) in spherical projection
  $P_x = \cos(\Phi)\cos(\theta)$
  $P_y = \cos(\Phi)\sin(\theta)$
  $P_z = \sin(\Phi)$

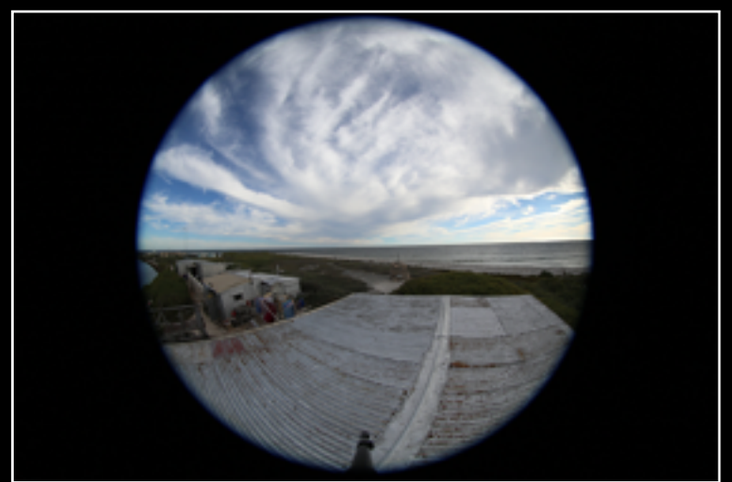
- 2. Given 3D vector P(x,y,z) what is the corresponding point on the spherical projection.
  $\Phi = \text{atan2}(P_z, \text{sqrt}(P_{x2} + P_{y2}))$
  $\theta = \text{atan2}(P_y, P_x)$





Content creation: Spherical projections

- We use a Canon 5D Mk II or III and Canon 8-15mm zoomable fisheye.
- Just 3 shots needed to create a full 360x180 spherical panorama.

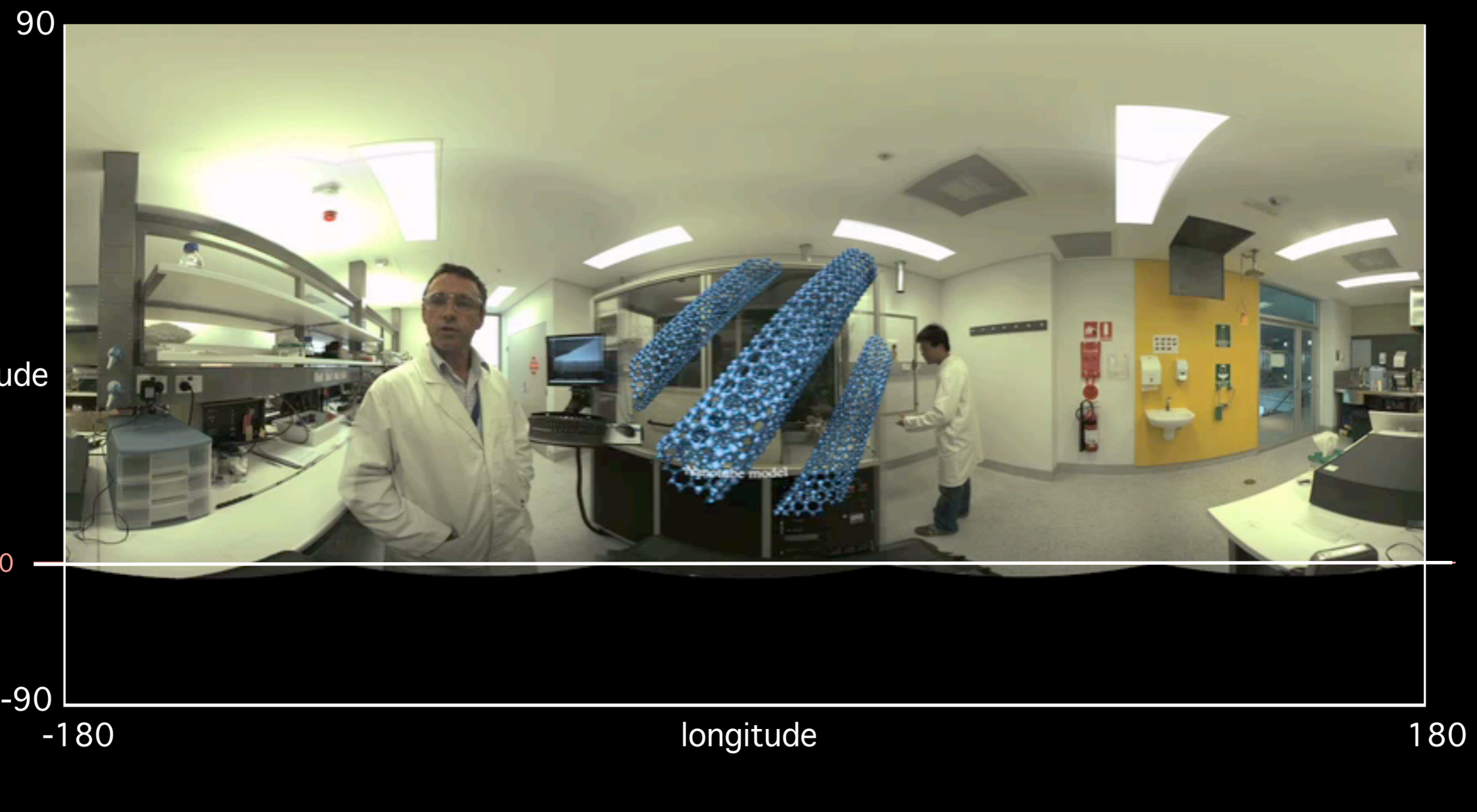


Content creation: Spherical video

- A number of options for capturing spherical video.
- With single camera options hard to capture sufficient resolution.
- We have a LadyBug-3 camera.
- Some interesting options now involving multiple GoPro cameras in cluster arrangement.

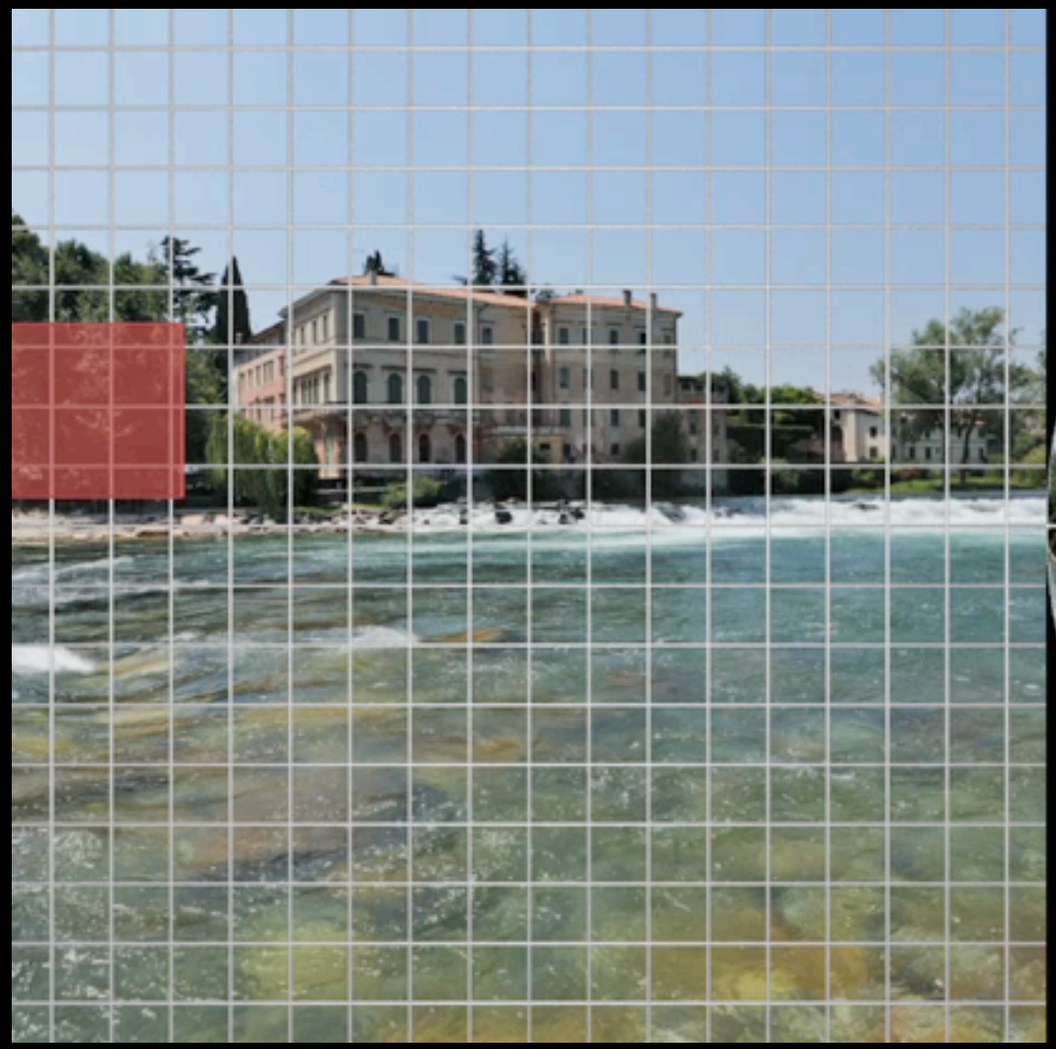
Content creation: LadyBug-3 camera

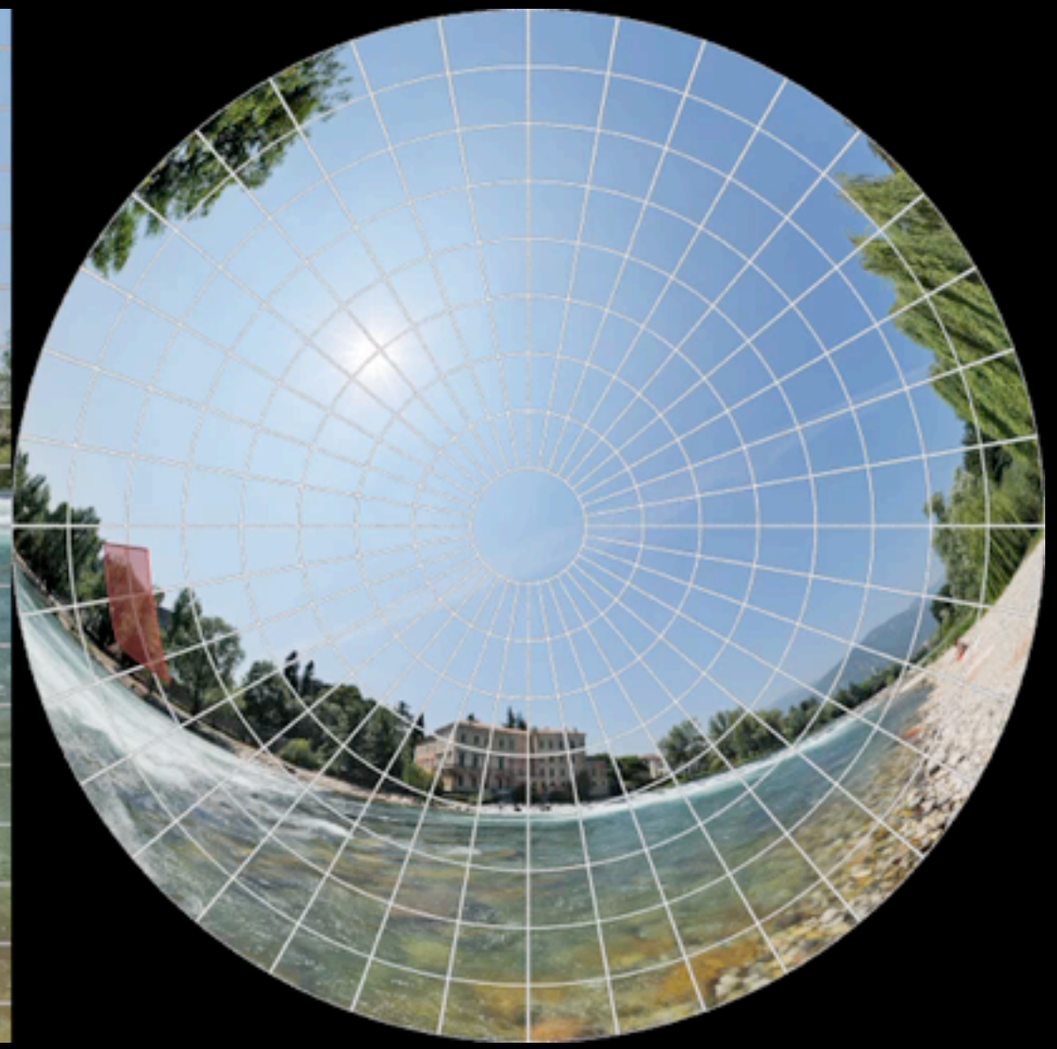
- Captures 360 degrees horizontally (longitude).
- Captures from the north pole to approximately -50 degrees vertically (latitude).
- [Show examples]



Content creation: Compositing

- Can’t often use standard packages because of non-rectilinearity of a fisheye projection.
- There are plug-ins for various packages to support fisheye coordinates.
- We use “Fulldome” plugin from Navegar for After Effects.



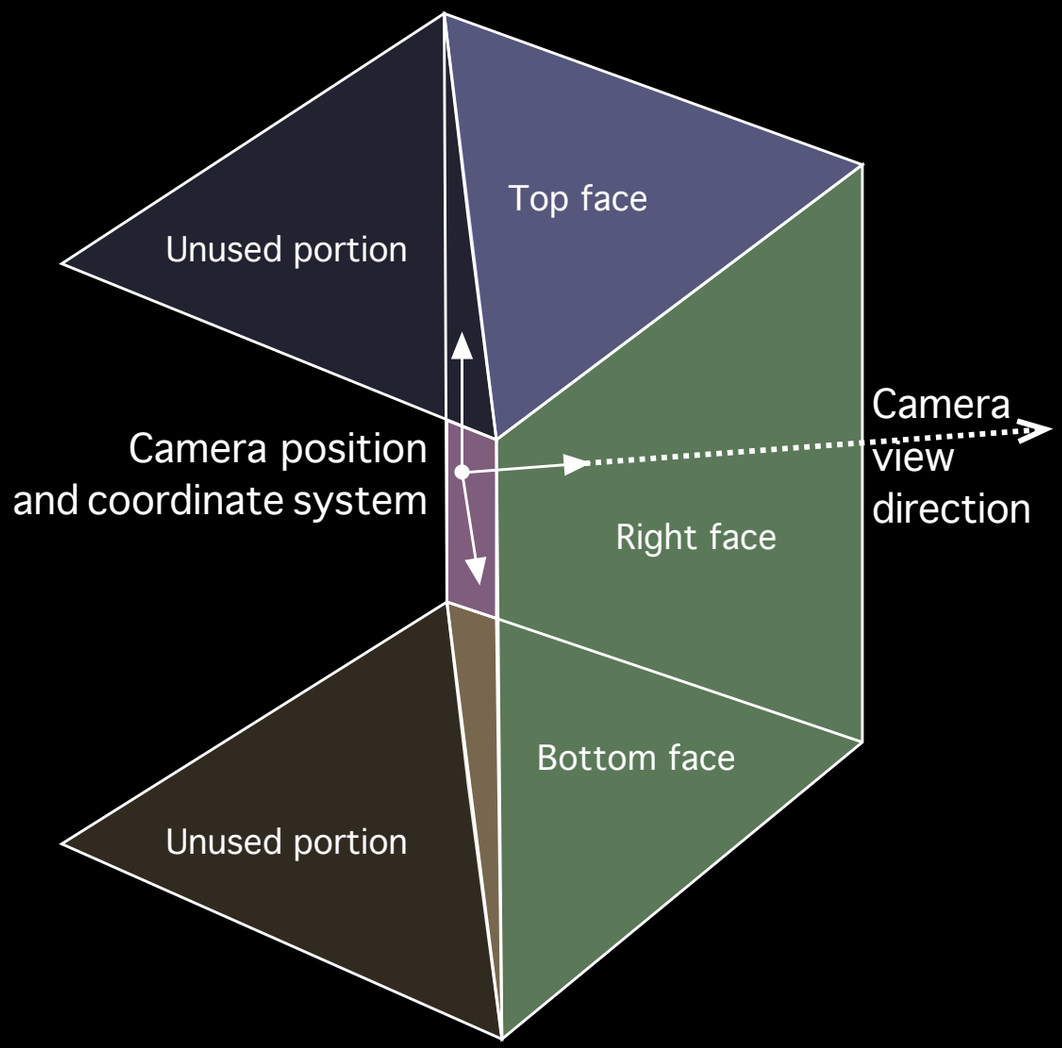


Content creation: CG (rendering)

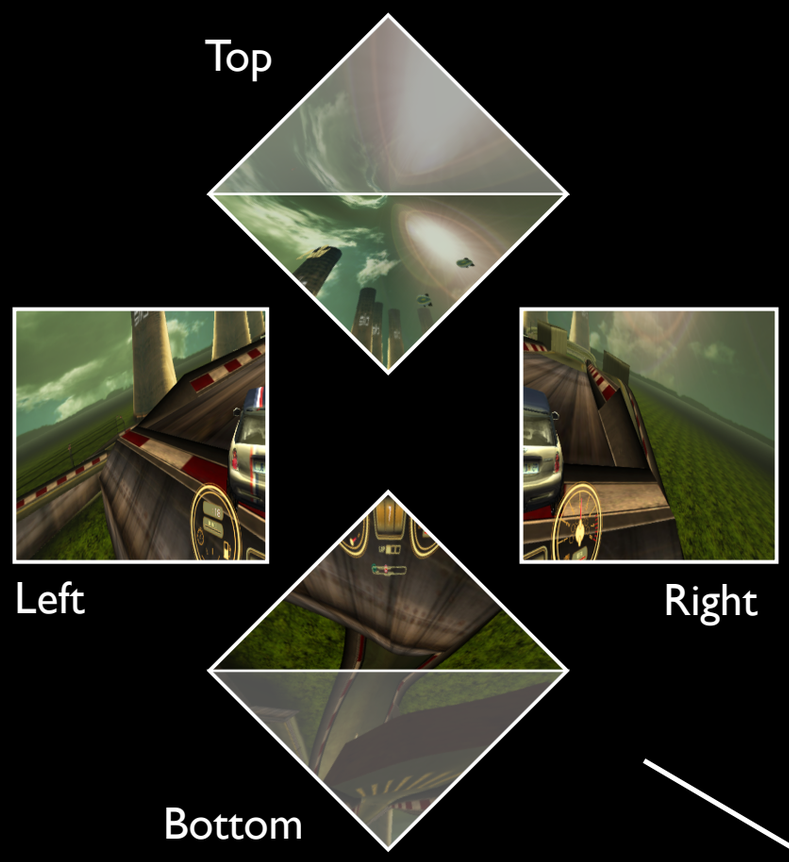
- Many/most rendering engines now support angular fisheye.
- For others there is generally a externally available plugin.
- Fallback position is rendering so called cubemaps.
- Fisheye assembly: cube2dome (my software), there are others.

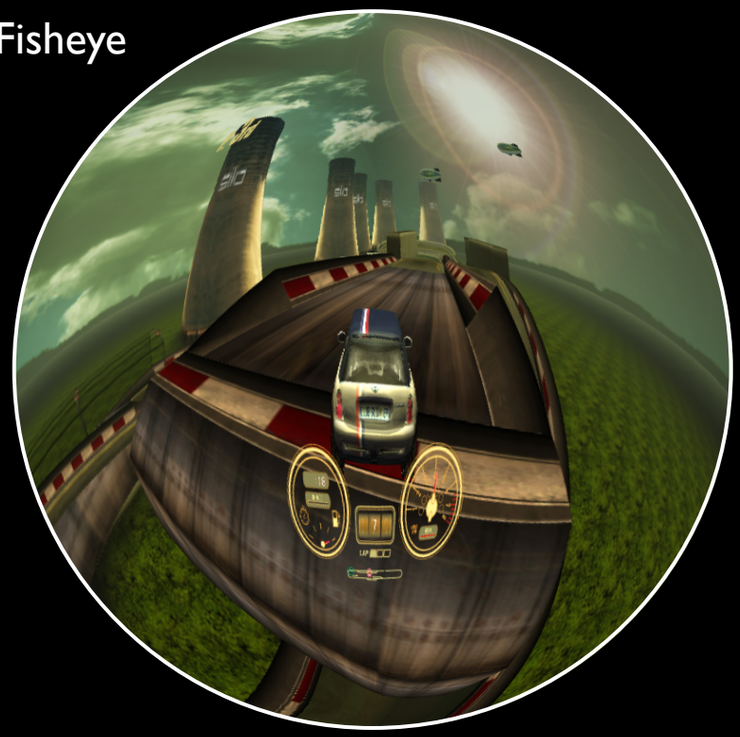
Content creation: Realtime

- Realtime APIs don't support fisheye projections.
- Two approaches, typically use multipass generation of cube maps.
- Approach used here is to render 4 views, frustums through the vertices of 4 faces of a cube centred at the camera.
- This is the approach used in Blender and Unity3D implementations.



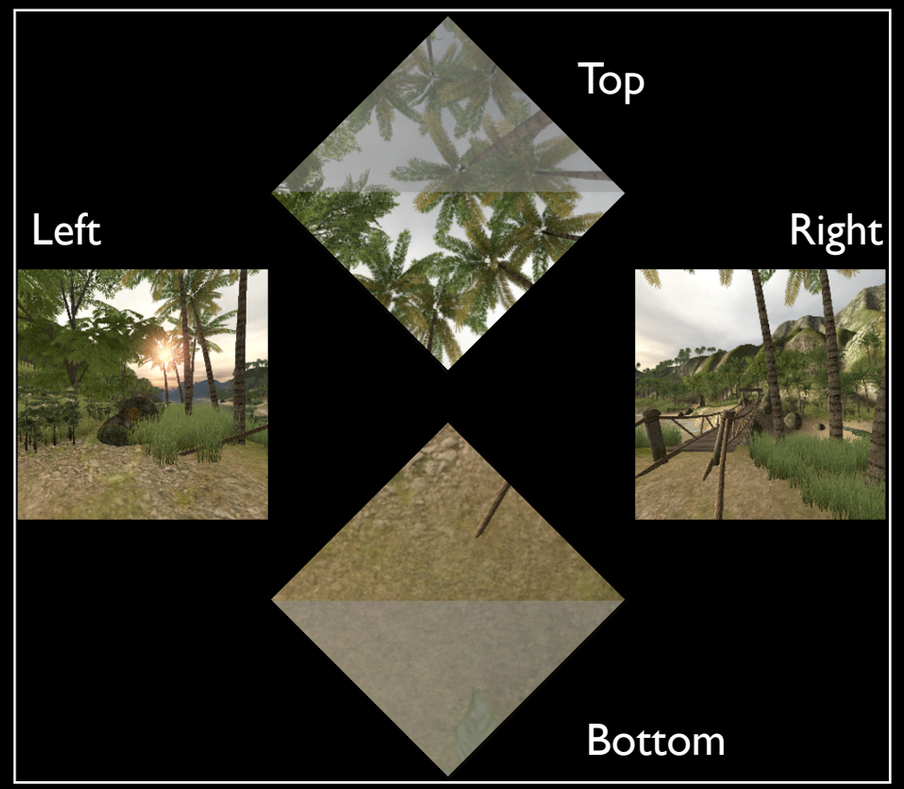
Content creation: Realtime in Blender Game Engine

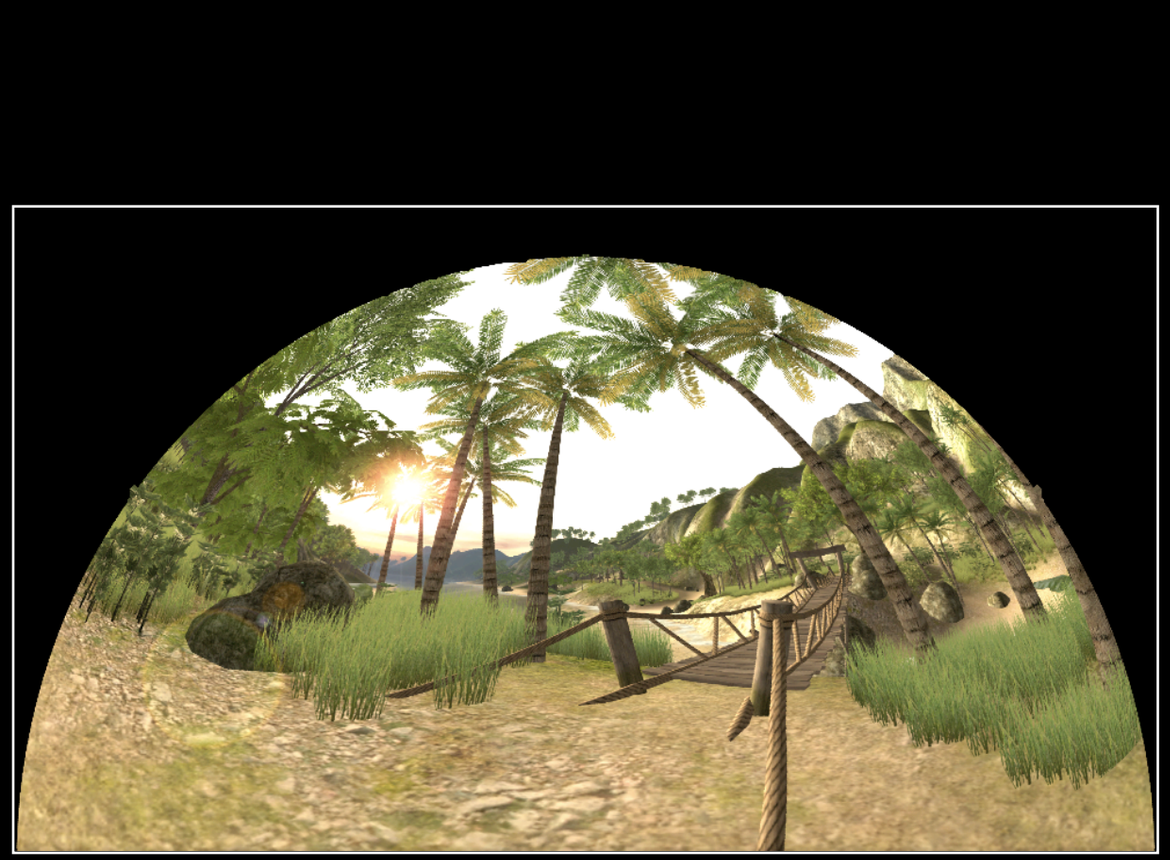




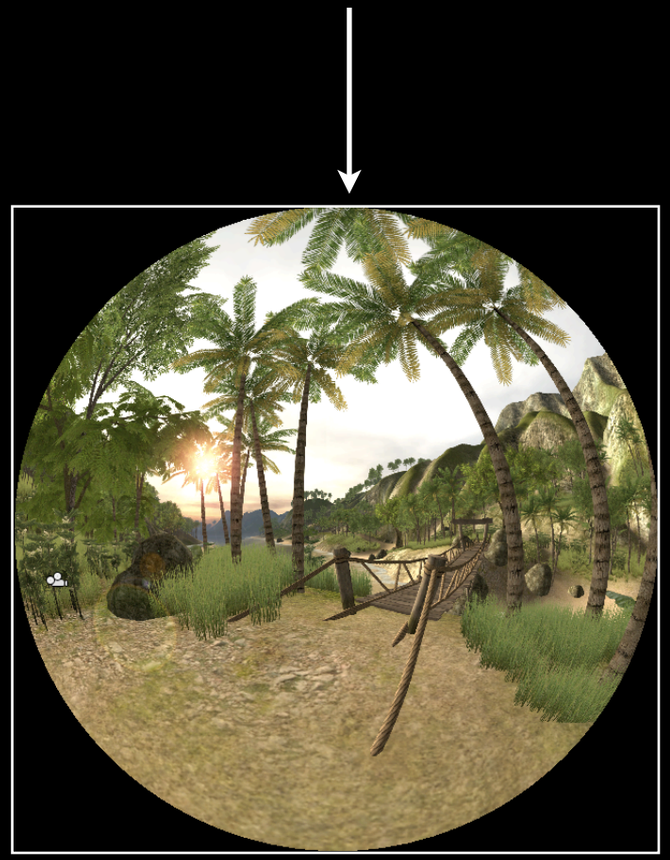
Content creation: Realtime in Unity3D

- Four initial passes implemented as “render-to-texture”, so requires Unity Pro.
- Possible to skip the fisheye step and apply the 4 textures directly to the warped texture mesh but the performance for the texture warping phase is negligible, less than 1 fps. This direct warping has some tricky implications for the design of the required texture meshes.





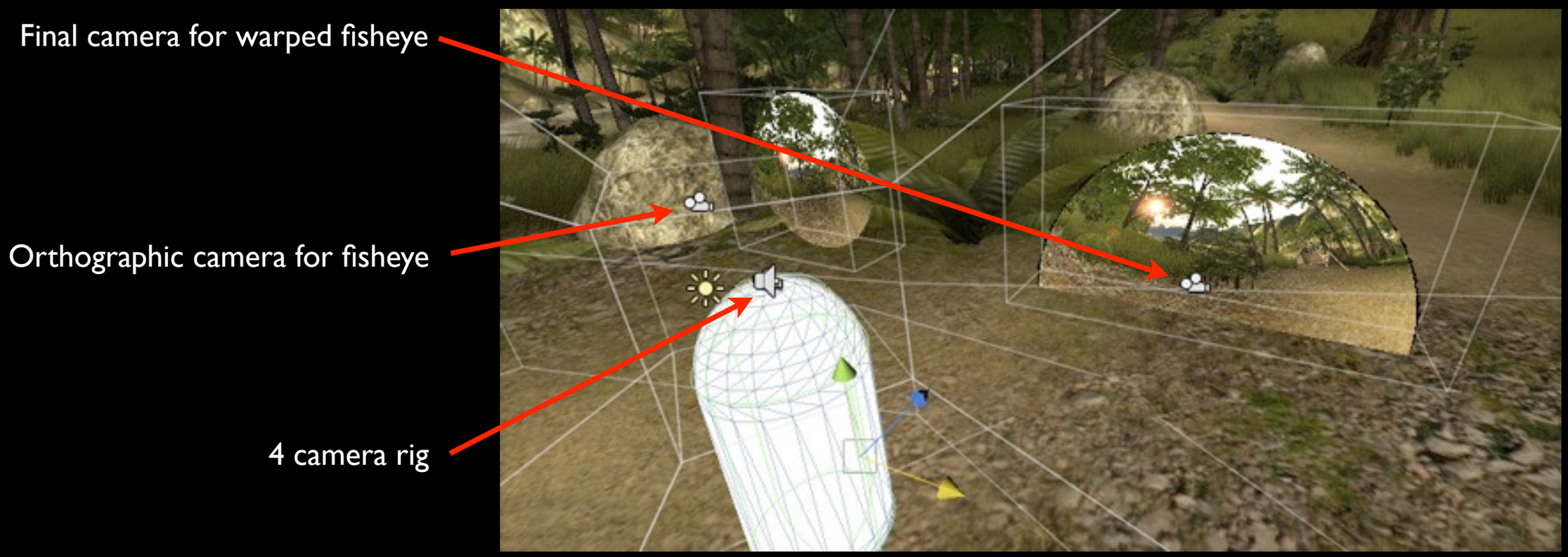
Warped fisheye



Fisheye

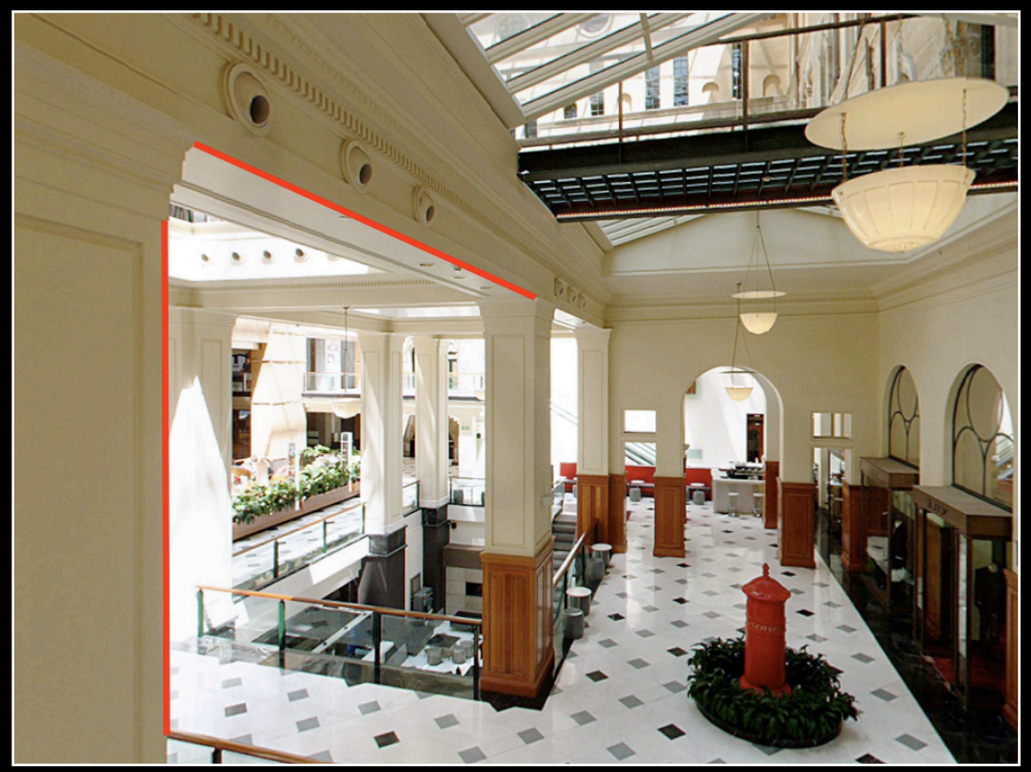
Content creation: Realtime in Unity3D

- What size textures to use in each stage? Two high and there are performance and aliasing effects. Too low and the full resolution of the iDome isn't being exploited.
- Cube face textures: 1024 pixels square. Fisheye texture is 2048 pixels square. Final image to be projected is HD, 1920x1080 pixels.



Content creation: Realtime using vertex shader

- Other approach is single pass (followed by warping) using vertex shader.
- A cunning trick: modify the position of each vertex such that the result when viewer with an orthographic camera is a fisheye image.
- Simple in concept but involves geometry tessellation which can be expensive.
- However there is a complication. A straight line in a standard perspective projection only requires knowledge of the two end points. A straight line is not "straight" in a fisheye projection.
- The solution is to tessellate all the 3D geometry being drawn. The optimal algorithm to do this is not at all trivial, inefficient tessellation results in a high geometry load on the graphics card.

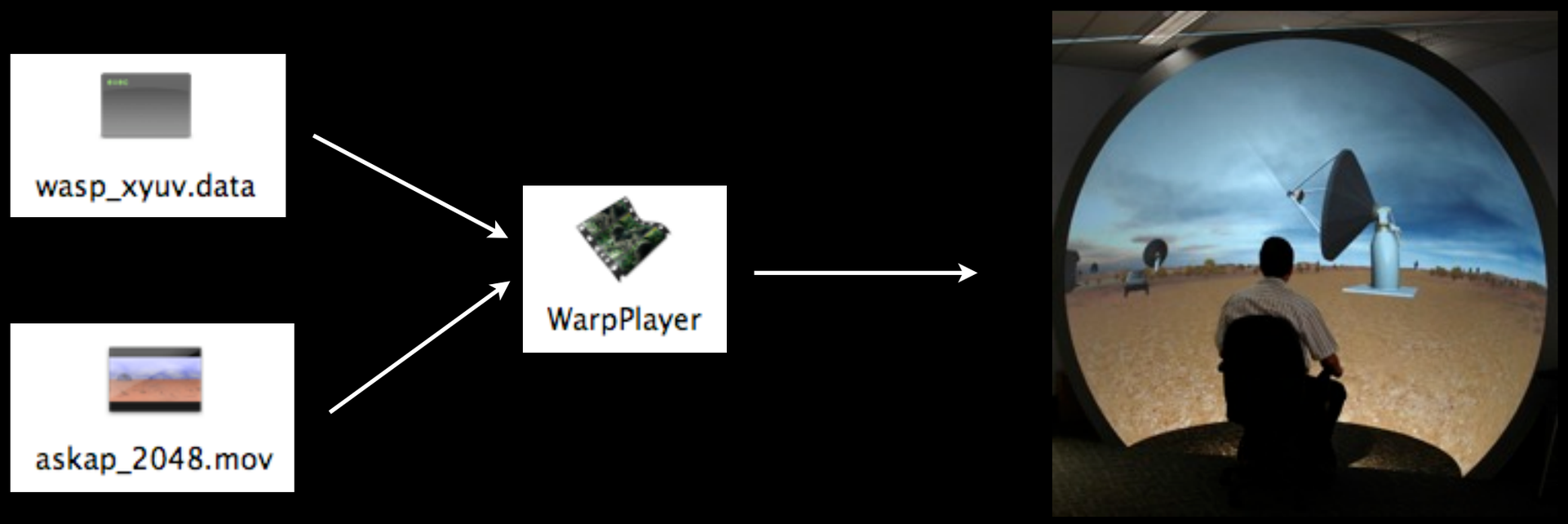


Software

- Various unix utilities: cube2dome, cube2sph, sphere2fish
- meshmapper: performs calibration and export warping mesh.
- warpplayer: fisheye movie player with warping on the fly.
- Quartz Composer: for movie and interactive spherical panorama playback.
- pbmesh: warp mesh implementation for Quartz Composer.
- Unity3D Pro: capable of fisheye and warped fisheye generation.
- Blender game engine: supports fisheye and warped fisheye generation.

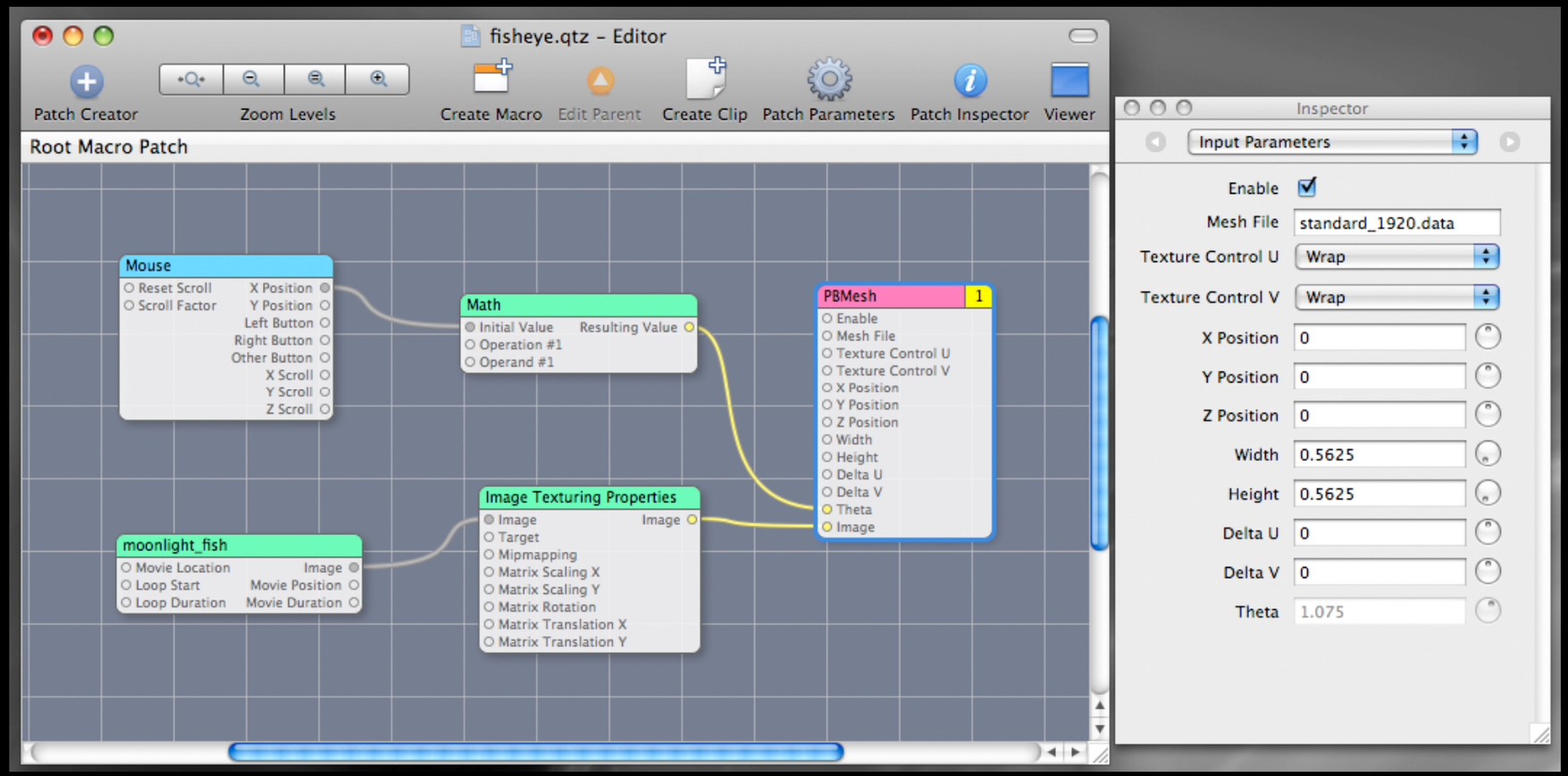
Software: warpplayer

- Takes a movie and a mesh file (looks for “default.data” by default) and plays the movie with each frame applied to the warping mesh.
- Optionally launches fullscreen.
- Warping file unique for each site, allows sharing of fisheye content.



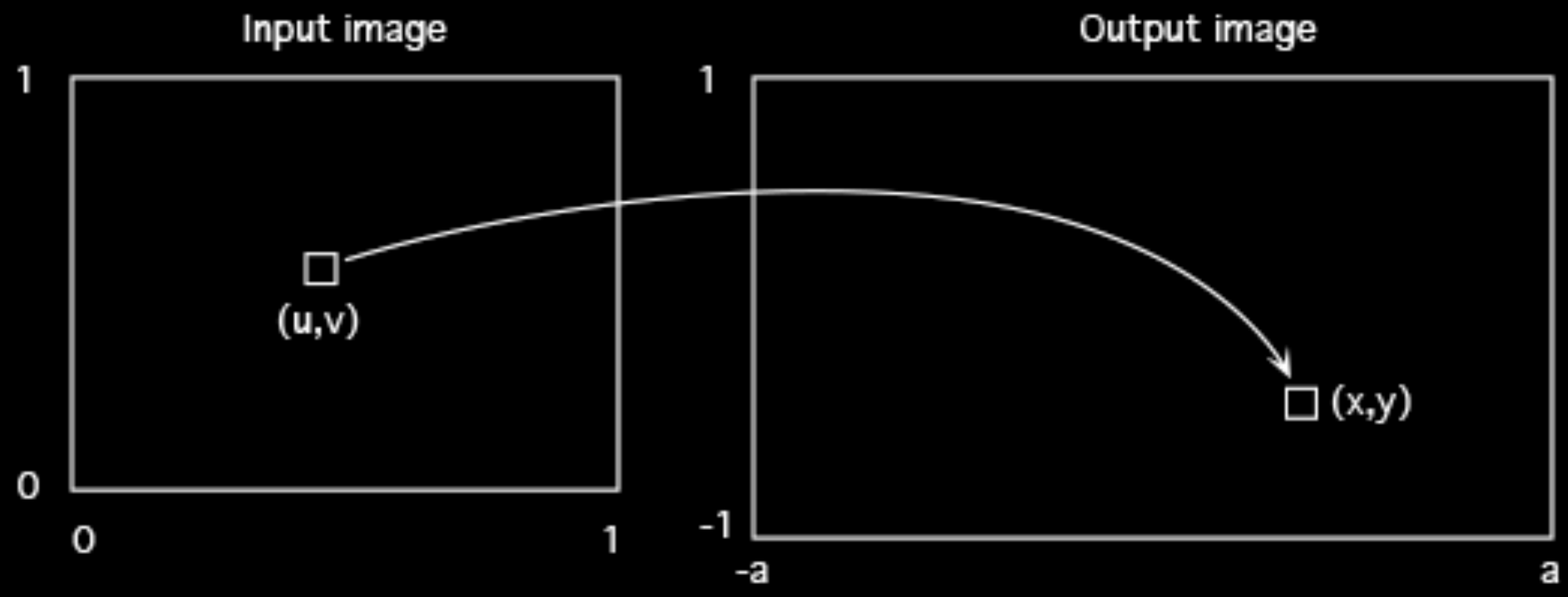
Software: QuartzComposer and pbmesh

- pbmesh implements warping within Quartz Composer.
- Uses the same warp mesh files as warpplayer, (and other tools).
- Ideal for scripting exhibitions with interactive elements, dynamic content, randomised components, transitions, etc.



Warping

- A regular grid.
- Each vertex consists of a position (x,y), texture coordinate (u,v), brightness (i).
- The positions are in normalised screen coordinates, -aspect to aspect horizontally, -1 to 1 vertically. Will appear full screen when viewer with the appropriate orthographic camera.
- Texture coordinate are from 0 to 1, these refer to the input image.
- Brightness values are from 0 to 1 (0 is black). Implemented as a multiplicative factor eg: glModulate().



Warp datafile

- First 2 lines consist of a header.
- First line is the type of input image.
  1 = planar image
  2 = fisheye image
  3 = cylindrical panorama
  4 = spherical panorama
  5 = cubic map
- Second line is the dimensions of the grid (nx,ny).
- Remaining lines are the node values (x,y,u,v,i).

```
2
100 60
-1.77778 -1 0.1608250 0.867370 0.530521
-1.74186 -1 0.1433430 0.850423 0.59831
-1.70595 -1 0.1264890 0.832400 0.670399
-1.67003 -1 0.1103900 0.813376 0.746497
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-1.59820 -1 0.0808694 0.772634 0.909462
-1.56229 -1 0.0676125 0.751080 0.995681
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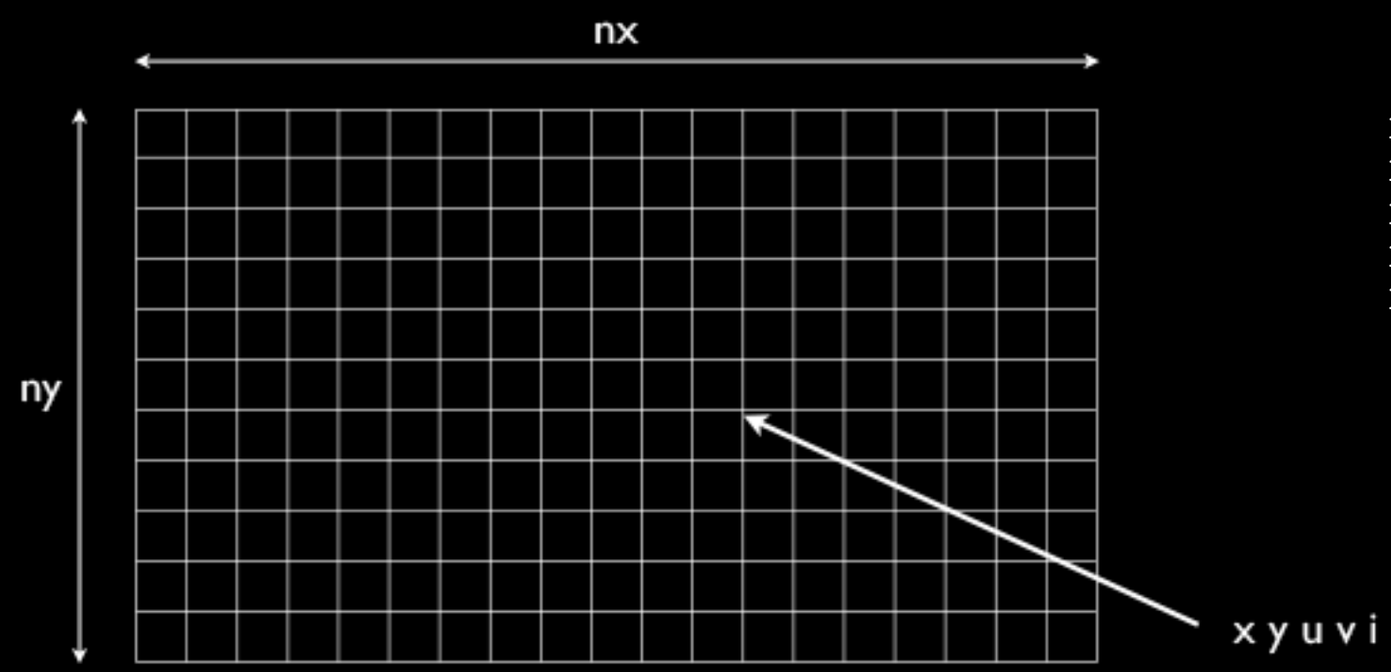


meshmapper

- Given a knowledge of the geometry of the system it creates a warp mesh.
- The user enters the geometric information as best they can and then adjusts the less certain parameters until a test patter looks correct.
- Test pattern is usually a polar grid.
- Parameters includes
  - the position of the components: projector, mirror (dome defines the origin).
  - radius of dome and spherical mirror.
  - optics of the projector: throw, aspect ratio, offset.
- Create warp mesh file data and optionally obj files for Unity3D.

General guidelines

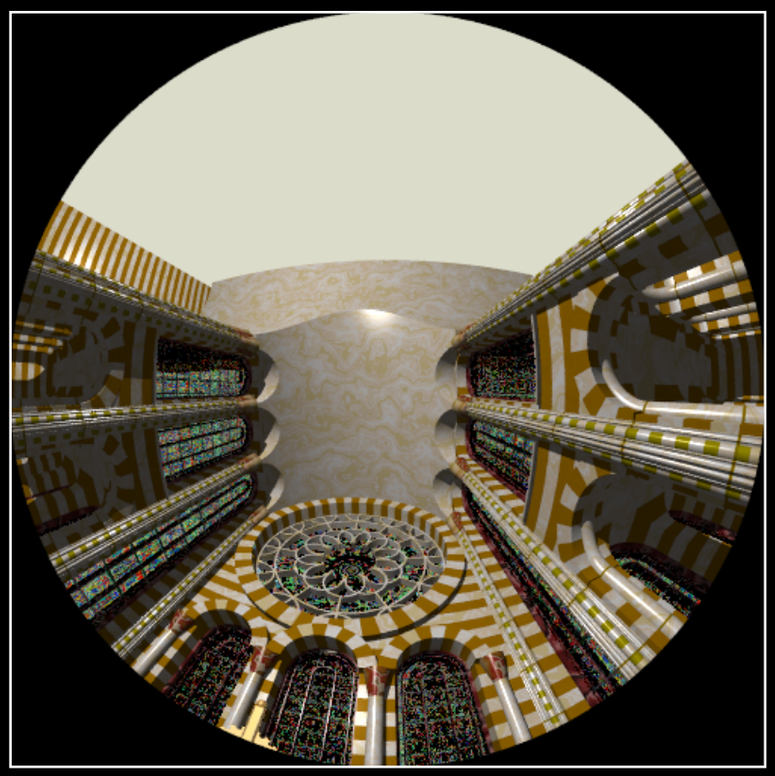
- Avoid large areas of bright colour, washes out the rest of the dome for a low contrast result.
- Motion is good, conveys depth through relative velocity cues.
- Generally slower motion than traditionally used.
- Place camera generating fisheye at the height of the intended viewer.
  Once one creates for fisheye, cylinder, stereo3D there is a close relationship between viewer and virtual camera. The display is a “window on the world”.
- The above principle means that the further one gets away from the position where the content was designed for, the greater the distortion.

- iDome content not suitable (generally) for planetarium style dome orientation.
  [Show example]
  Build in the flexibility to tilt fisheye orientation into realtime-interactive content.

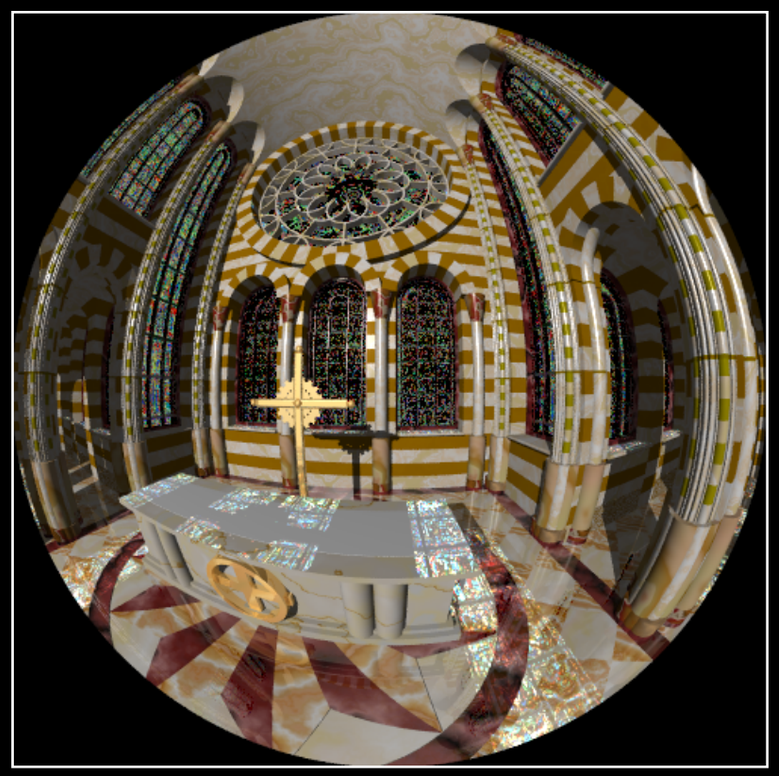
Content sharing considerations: Dome angle

- Dome angle matters.

30 degree tilt: OmniMax

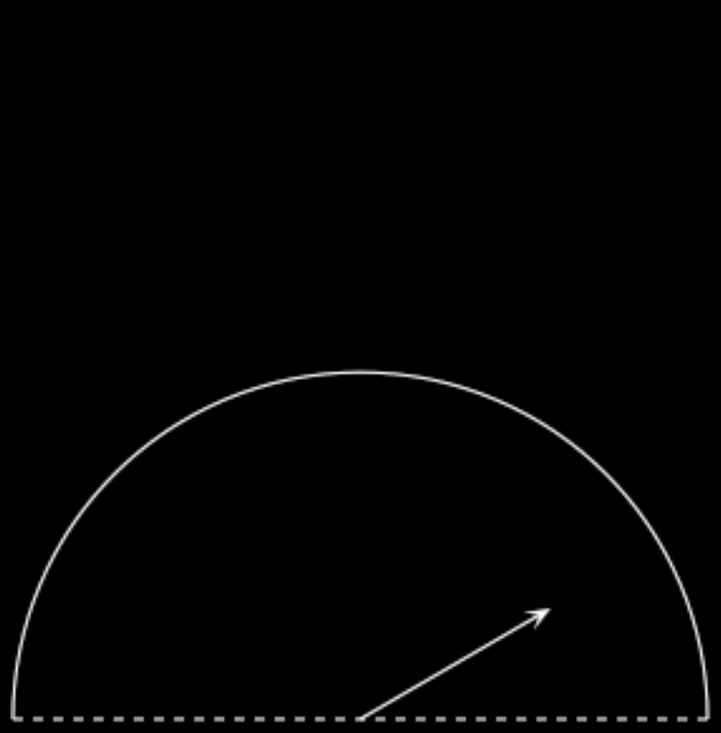


Traditional planetarium

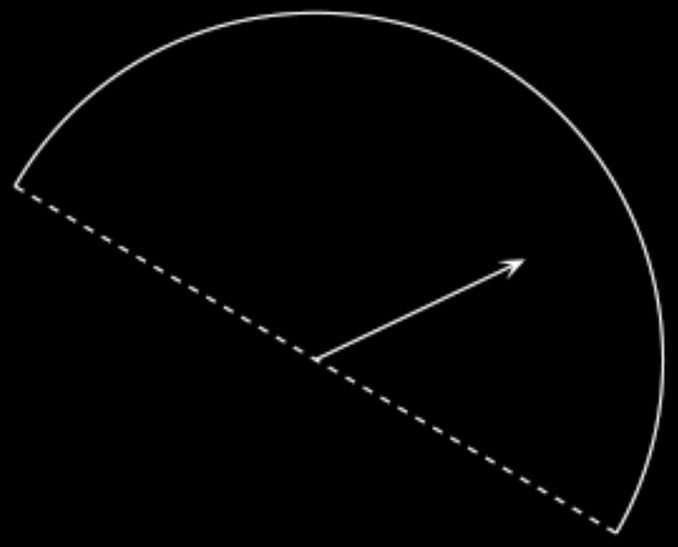


90 degree tilt: upright dome

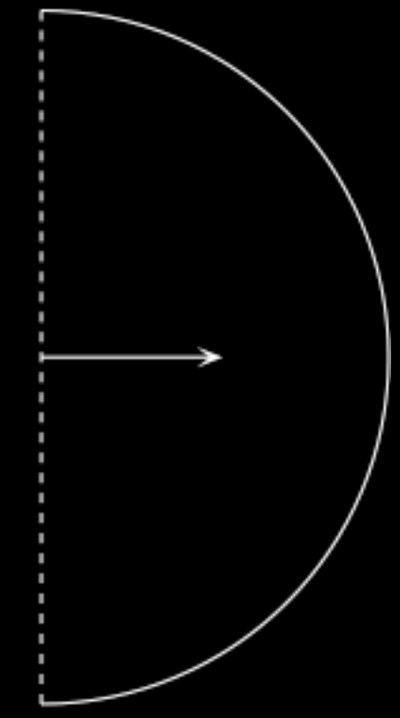
Content sharing considerations: Centre of attention



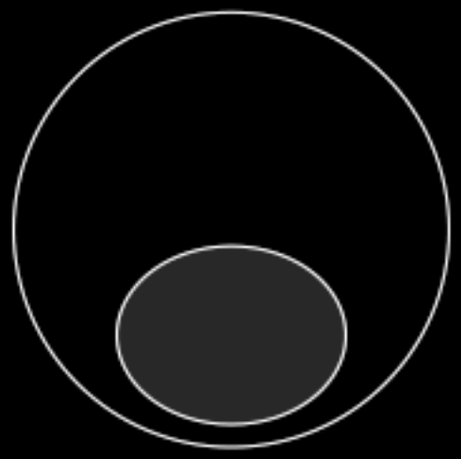
Unidirectional planetarium

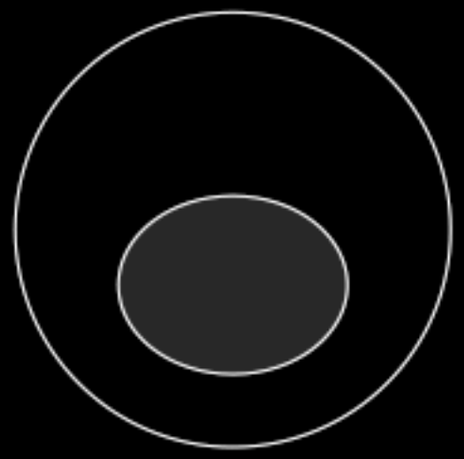


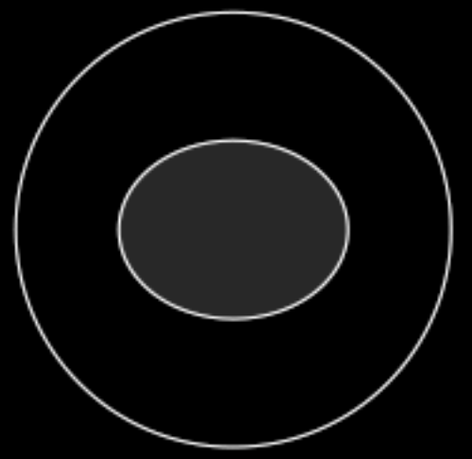
OmniMax



iDome

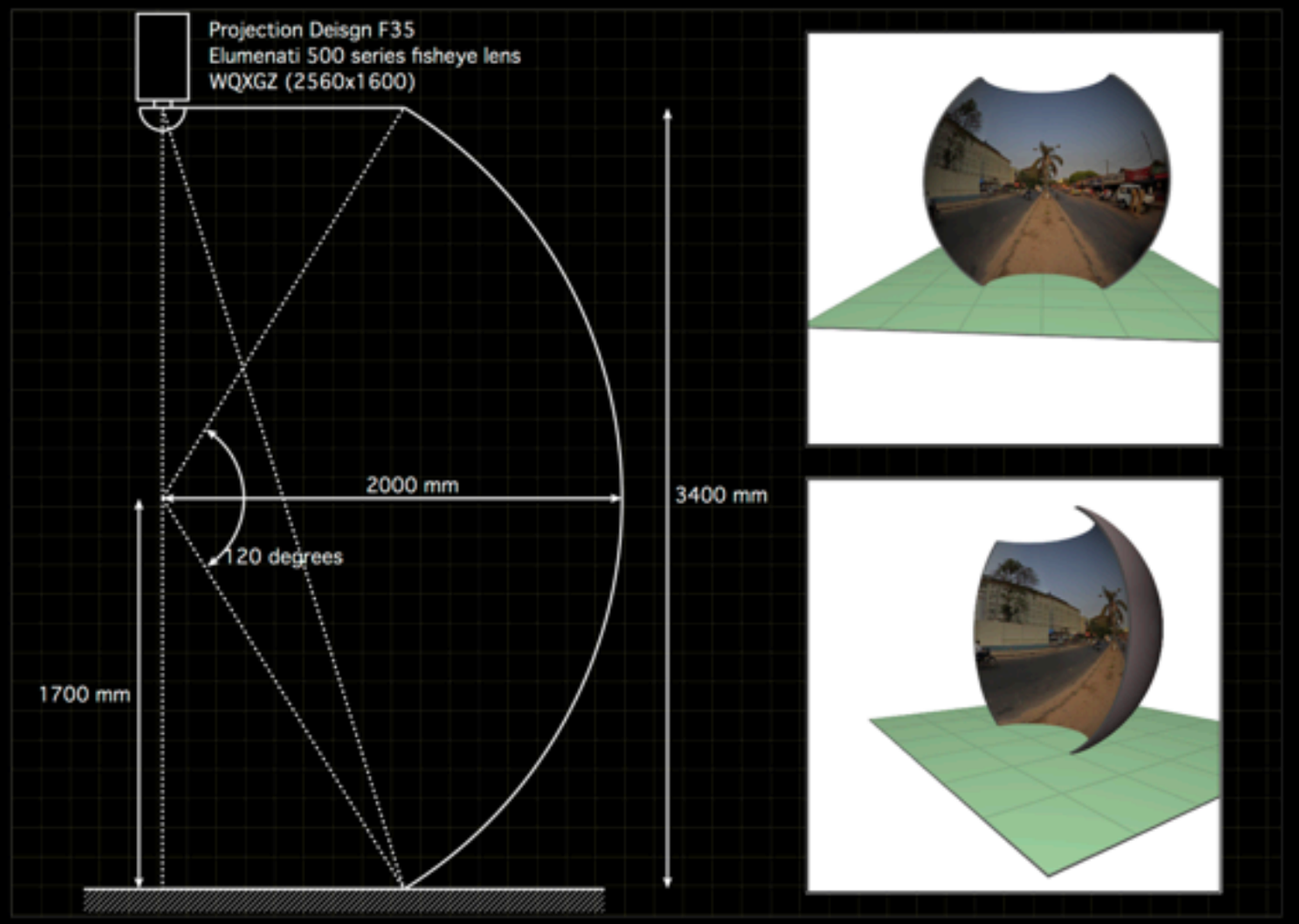






Other domes in WA

- Horizon the Planetarium: Scitech.
- Inflatable domes at Scitech and a few private operators.
- iDome at Curtin Arts School.
- iDome at iVEC@UWA.
- Soon to be installed dome in visualisation space at John Curtin Gallery.
- Gravitational Discovery Centre



Further reading

- Using a spherical mirror for projection into immersive environments.
  http://paulbourke.net/papers/graphite2005/
  Proceedings of the 3rd international conference on computer graphics
  and interactive techniques in Australasia and South East Asia, pp 281-284, 2005.

- Low Cost Projection Environment for Immersive Gaming.
  http://paulbourke.net/papers/jmm/
  JMM (Journal of MultiMedia), Volume 3, Issue 1, pp 41-46, May 2008.

- iDome: Immersive gaming with the Unity game engine.
  http://paulbourke.net/papers/cgat09b/
  Proceedings of the Computer Games & Allied Technology 09 (CGAT09),
  Research Publishing Services, ISBN: 978-981-08-3165-3, pp136-143, 2009.

Online resources

- Yahoo group: small_planetarium
  http://tech.groups.yahoo.com/group/small_planetarium/

- Yahoo group: fulldome
  http://groups.yahoo.com/group/fulldome/

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

- Wikipedia page on fulldome
  http://en.wikipedia.org/wiki/Talk:Fulldome