Omnidirectional stereoscopic fisheye images for immersive hemispherical dome environments.

Paul Bourke
WASP, UWA

Introduction

- My role: providing science visualisation expertise and services to university scientists.
  - The data involved in invariably well suited to existing within a virtual world.
  - There is a strong desire to engage with this data collaboratively within 3D environment.
  - Providing engaging environments has benefits for public outreach and education.
- Increasing moving away from high end (expensive) software/hardware and leveraging the investment being made in the gaming industry, most notable gaming engines.
- Claim: While there are many components required to provide an engaging virtual experience, one is to exploit the way we experience the real world.
- Outline
  - Exploiting the human visual system
  - Existing options for creating stereoscopic fisheye
  - Fundamental stereoscopic theory
  - Omnidirectional stereoscopic panorama and now fisheye
  - Examples
- This talk demonstrates “proof of concept”, talk this afternoon demonstrates current gaming capability in the iDome.

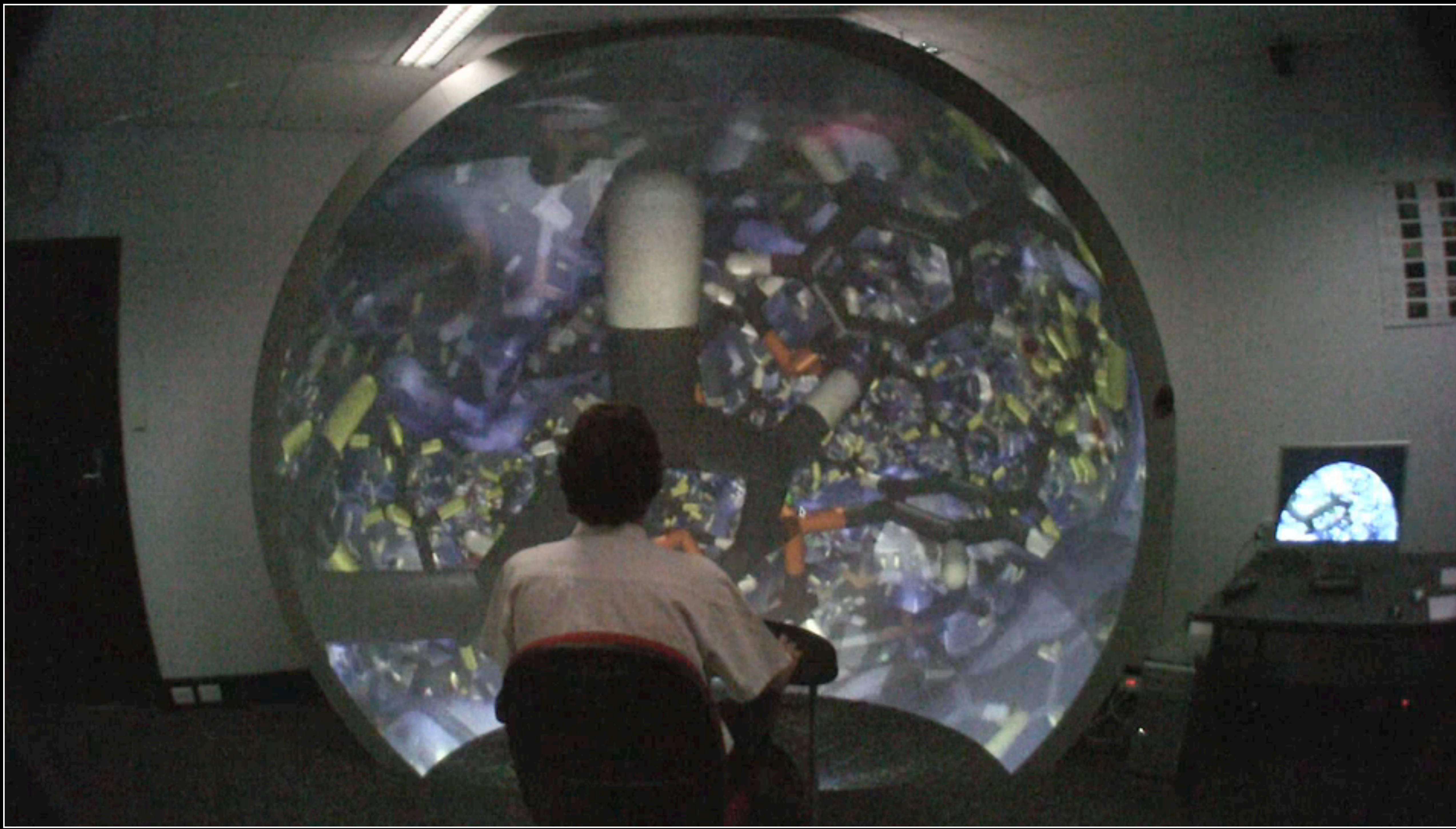
Peripheral vision and stereopsis

- Our visual system with which we explore our real world has two characteristics not often employed together when engaging with a virtual world, for example, when gaming.
- The first is the 3D depth perception that arises from the two different images our visual cortex receives from our horizontally offset eyes.
- The second is our peripheral vision that gives us visual information up to almost 180 degrees horizontally and 120 degrees vertically.
- While each of these is often exploited individually, there have been very few attempts to engage both.
- The most common are stereoscopic cylindrical displays but even if they engage enough of our horizontal field of view they generally don't fill our vertical field of view. Very rarely do they occupy more than 30 or 40 degrees, so the viewer still sees the real world, notably the frame of the cylinder.
- The obvious exception is the CAVE but that is prohibitively expensive for gaming applications.

Stereoscopic experience in a hemispherical dome

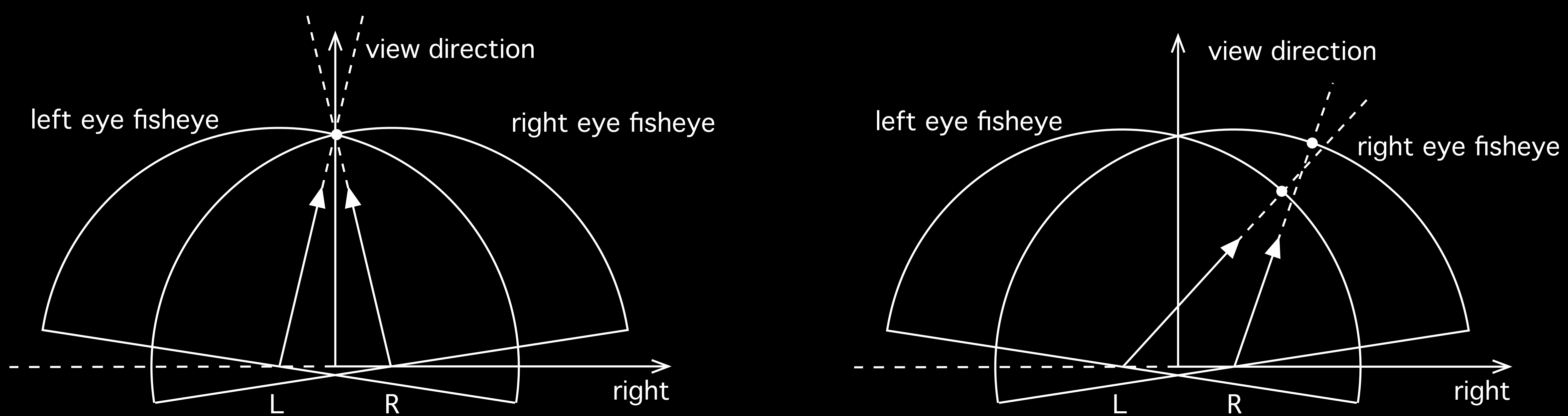
- A hemispherical dome with the user at the center is an environment where the virtual world occupies the entire visual field of view.
- A hemispherical surface has advantages over multiple planar surfaces that might surround the viewer. The hemispherical surface (without corners) can more readily become invisible. This is a powerful effect in a dome where even without explicit stereoscopic projection the user often experiences a 3D sensation due to motion cues.
- How might one create optimal stereoscopic fisheye pairs for such an environment?
- Optimal
  1. Be able to look around without head tracking.
  2. Uses by multiple people simultaneously.
  = Omnidirectional stereoscopic pairs.
- There are a number of potential approaches
  - fisheyes from two positions tilted inwards
  - offaxes fisheyes
  - omnidirectional fisheyes presented here
- Aside: depth perception is often experienced in a dome without explicit stereoscopic imagery. When there is only virtual imagery and the screen surface is not seen, the visual cortex will use other normally secondary cues to create a sense of depth.

Example of 3D depth effect in the iDome



Naive approach: offset fisheyes tilted (rotated) inwards

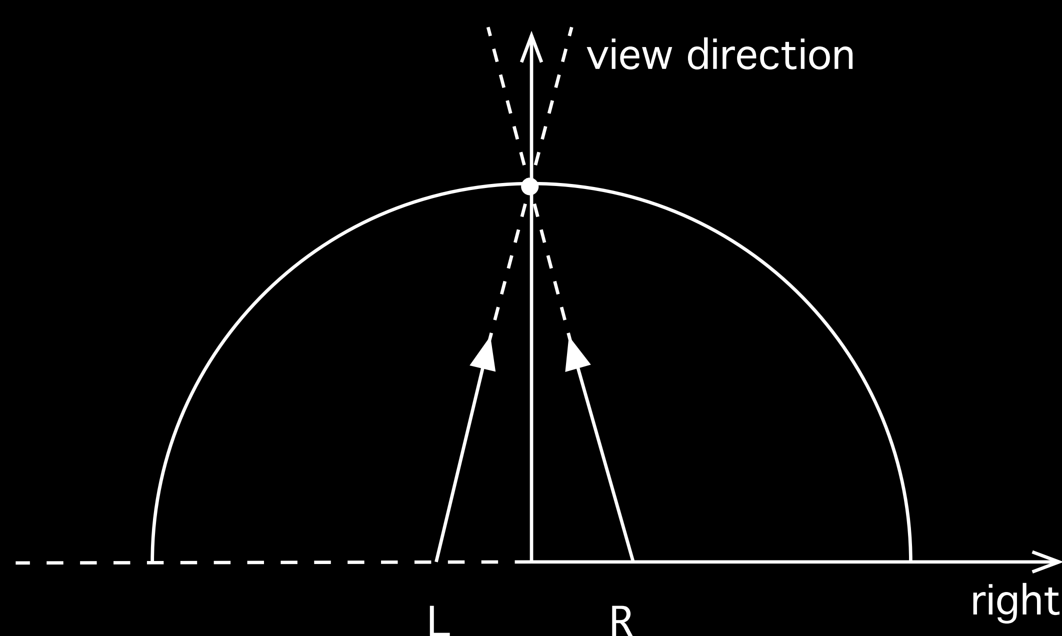
- One might imagine generating two fisheye projections, each from a horizontally offset position. The fisheye cameras are be tilted inwards about their respective centers to set the right zero parallax depth.
- This can also be imagined as a rotation about the vertical axis of the fisheye hemisphere.
- While this will work for a narrow range of angles, as one looks further away from the center of the fisheye the stereoscopic error increases.
- When looking perpendicular to the central direction of the fisheye, there is no parallax at all and a scaling error since one camera is closer than the other to any objects.
- Note that over-rendering (fisheye angle > 180) can be used to avoid gaps on the sides of each fisheye.

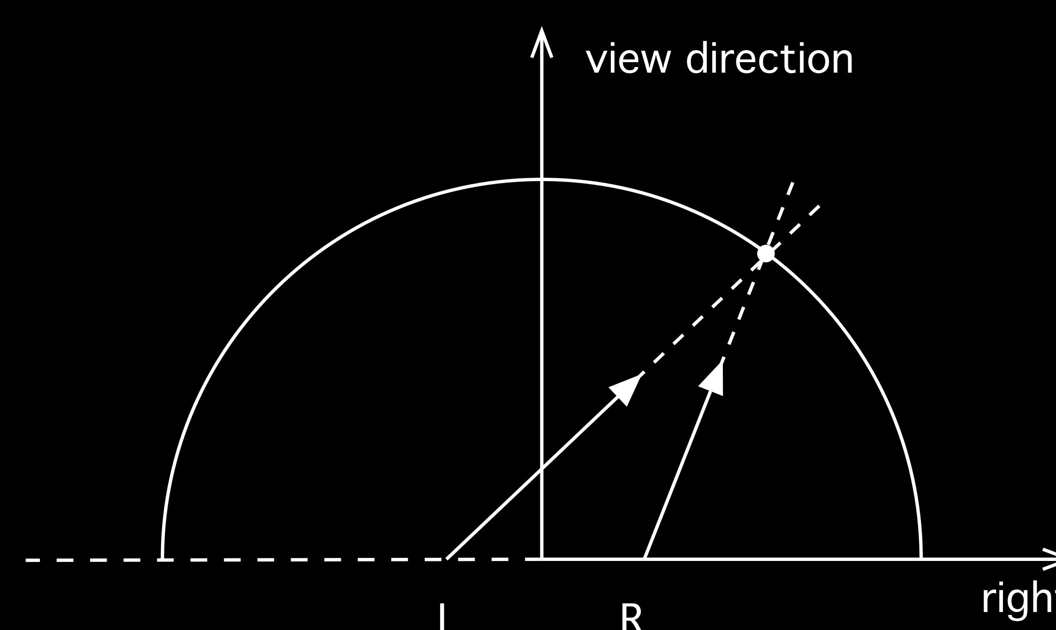


[Exaggerated view for illustration purposes only]

Offaxis fisheye pairs

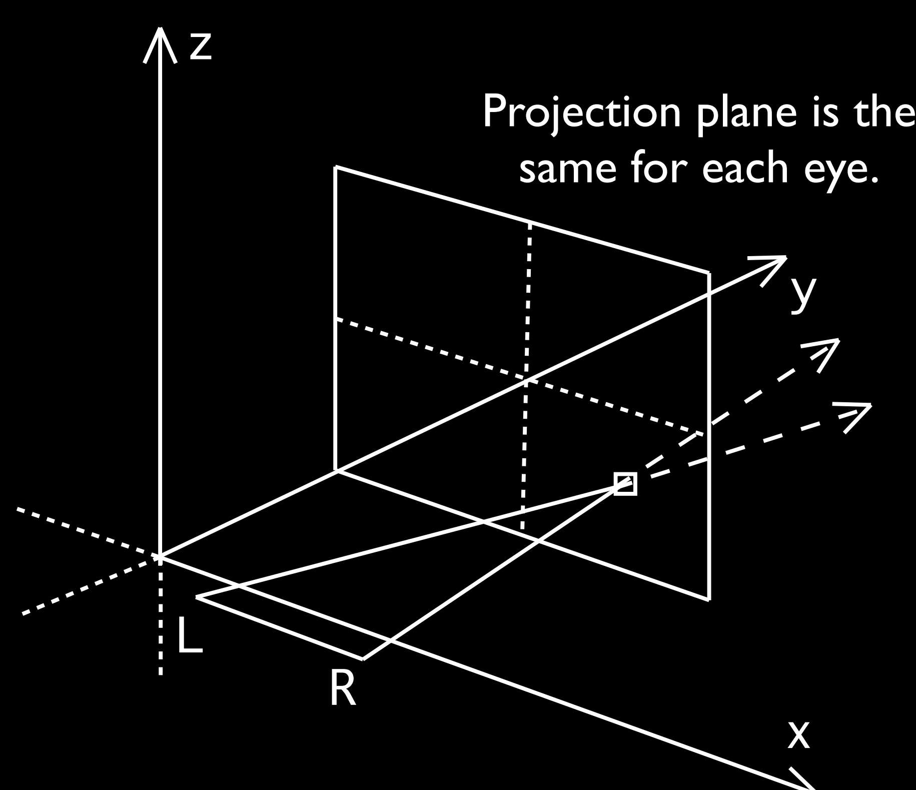
- So called offaxis fisheye is often used to create fisheye images for projection into a dome when
  1. The projector with fisheye lens is not at the center of the dome.
  2. The viewer is not at the center of the dome.
- In an offaxis fisheye rays through each position on the hemisphere emanate from a position other than the center of the hemisphere.
- Same errors at the poles as offset / rotated fisheye projections, including scale errors on the sides.
- The best approach for a forward looking viewer.

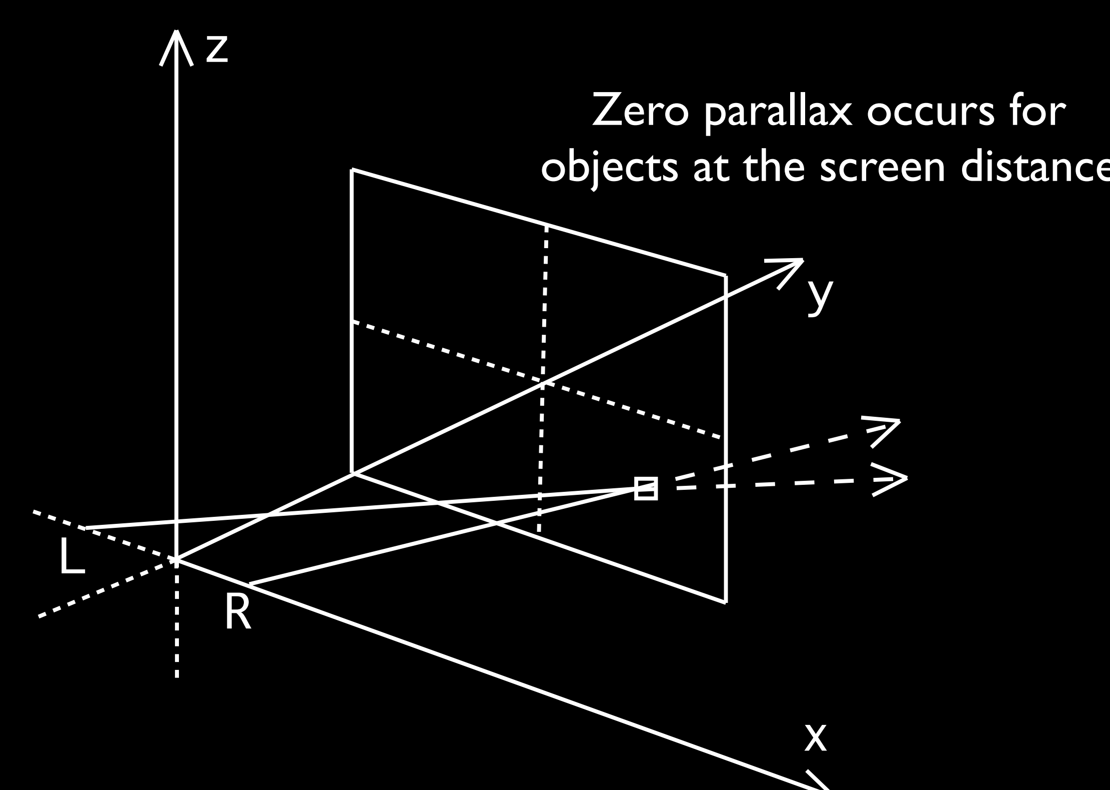




Model for generating a stereoscopic image in any environment

- General approach to creating correct stereo pairs involves considering the viewer position with respect to the projection surface.
- A ray from each eye of the viewer through every position (pixel) on the projection surface extends into the scene.
- Depending on what each ray encounters determines the colour at that pixel.
- The best way to imagine this is as the viewer looking through a window on the world. The relationship of the viewer to the window determines what can be seen.



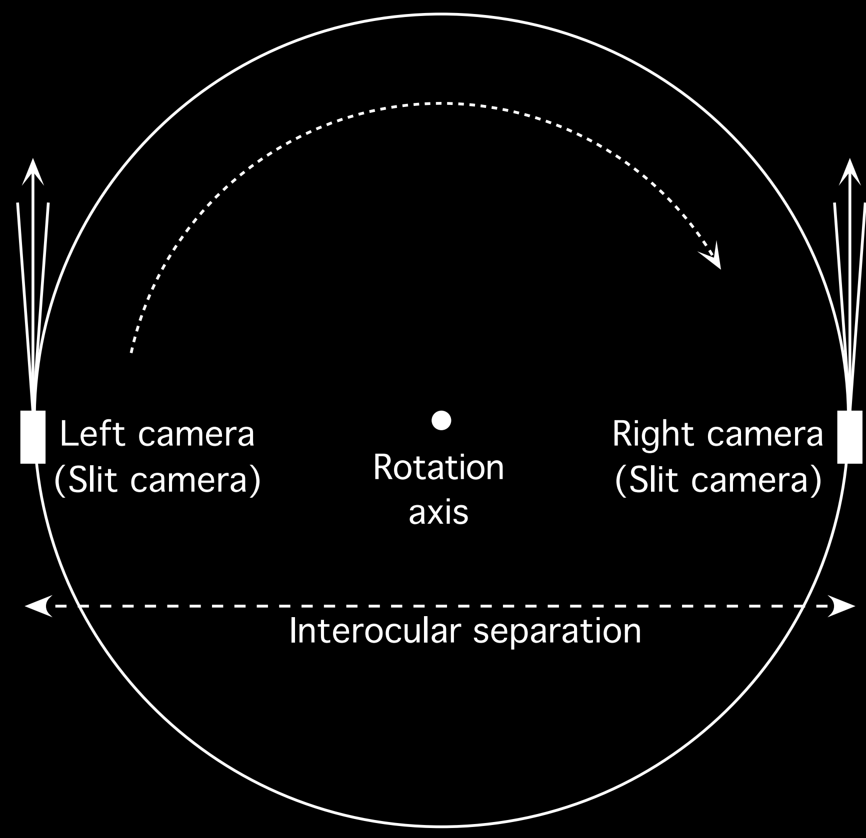


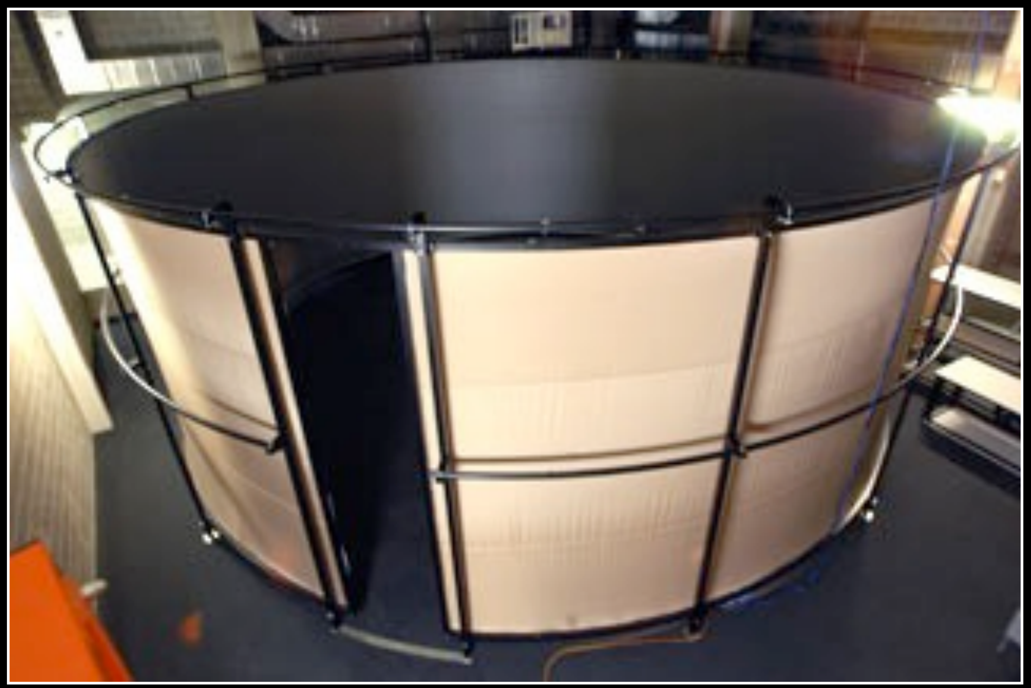
Stereoscopic errors due to viewer position

- Stereoscopic depth perception is only strictly correct for a single viewer position.
- Only with very careful design can true 1:1 scale and real depth perception be achieved. Requires a precise identity relationship between the viewer / screen and camera / projection plane.
- For multiple viewers, they cannot all get a truly correct stereoscopic view.
  For example in a stereoscopic enabled picture theatre.
- As a single viewer moves further away from the correct viewing position they get an increasingly distorted view.
- If this is important (eg: CAVE) then it is solved with a device that tracks the viewers position and adjusts the camera frustums correspondingly. This inherently reduces the viewing to a single person. Multiple viewers get distorted views the further they are away from the tracked user and the more they are looking in a different direction.
- But errors are often acceptable, a acceptable sensation of depth can be created without it being strictly correct. Can one then produce a stereoscopic viewing system that:
  1) surrounds a number of viewers and gives them all an acceptable stereoscopic experience
  2) allows one or multiple viewers to each look in different directions?

Precedent: Omnidirectional stereoscopic panorama

- Cylindrical displays, possibly all around the viewer have been successfully developed, in some cases this includes stereoscopic cylindrical displays.
- Techniques exist for creating so called omnidirectional stereoscopic panorama pairs, both CG/ rendered and photographically.
- That is, multiple viewers can occupy the same cylindrical display, each looking in different directions without the need for head tracking.
- The stereoscopic effect is correct towards the center of gaze and the error increases away from that gaze direction. But this is true for any gaze direction. This is acceptable because the glasses limit the field of view and we don't see stereoscopically in our peripheral vision anyway.





AVIE, iCinema

Example of omnidirectional stereoscopic cylindrical projections

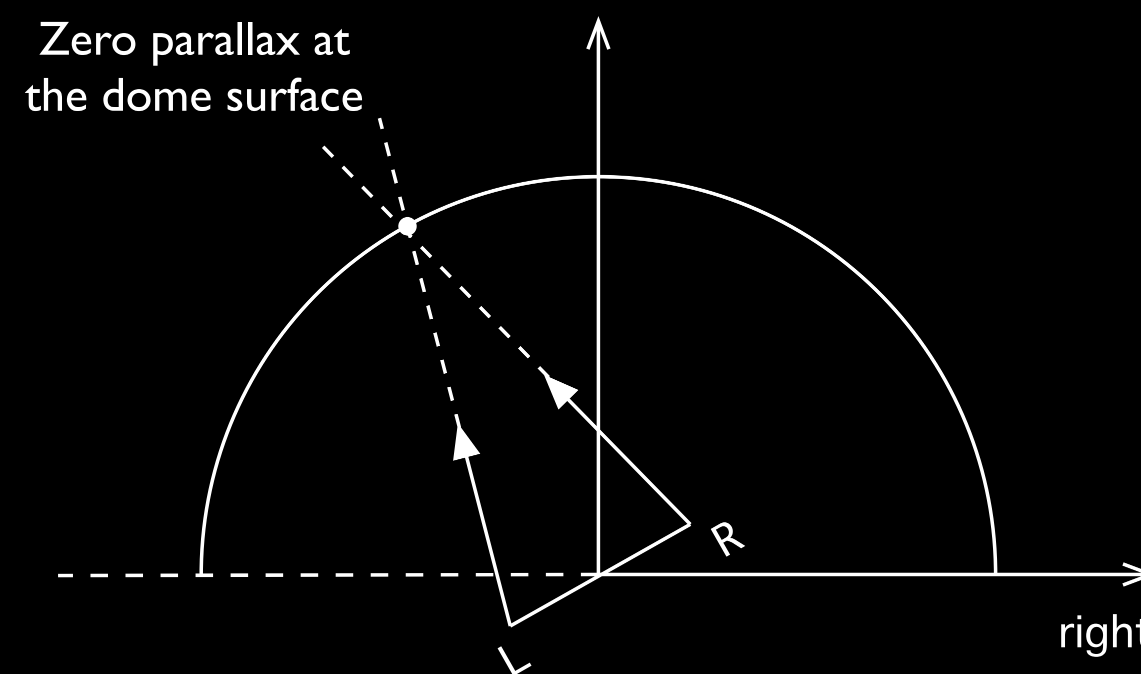
Left eye

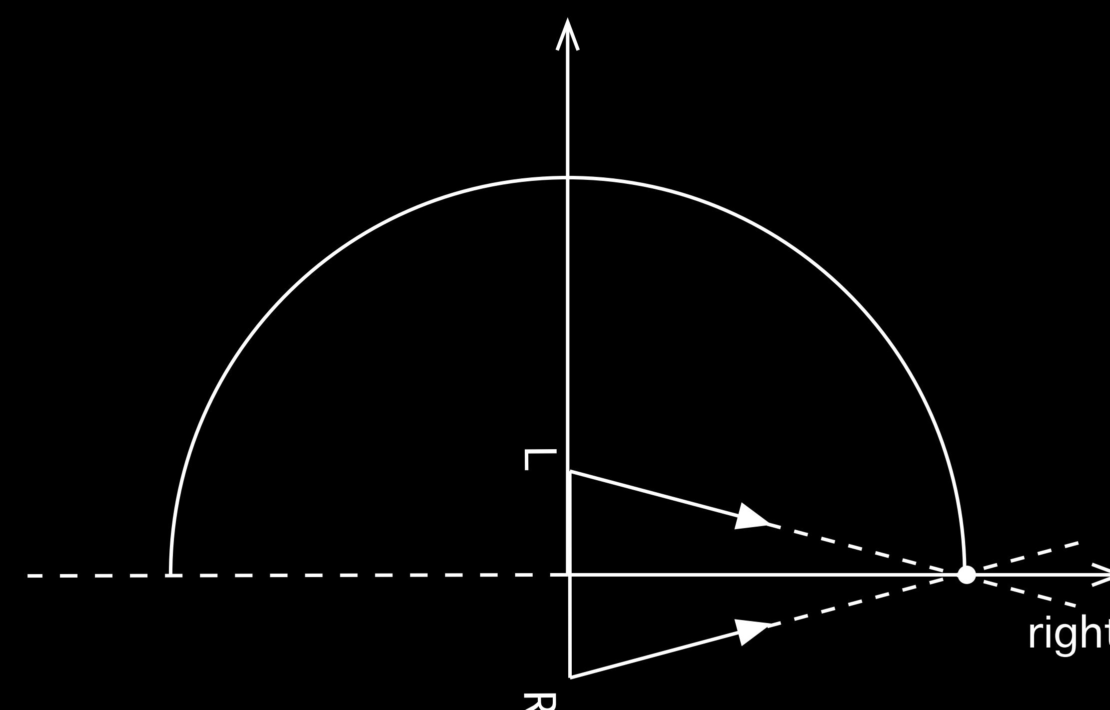
Right eye

Photographs courtesy Peter Morse

Model for omnidirectional stereoscopic fisheye projections

- Employ the basic stereoscopic principles discussed earlier.
- For every position on the surface of the hemisphere, consider rays from each eye through that position and into the scene.
- Set the value of that pixel accordingly.
- Key difference: The line between the eyes is kept perpendicular to the surface of the hemisphere, the "up" vector is preserved.
- As one swivels ones head around the dome surface the line between ones eyes stays roughly perpendicular to the dome.
- The result is a (locally correct) stereoscopic image irrespective of where the user is looking.
- Multiple viewers in a large dome can each be looking in a different direction. Distortion still increases as one moves away from the central position.





Derivation of rays from eye through each pixel

For the proposed omni-directional fisheye projection the vector into the scene is given by

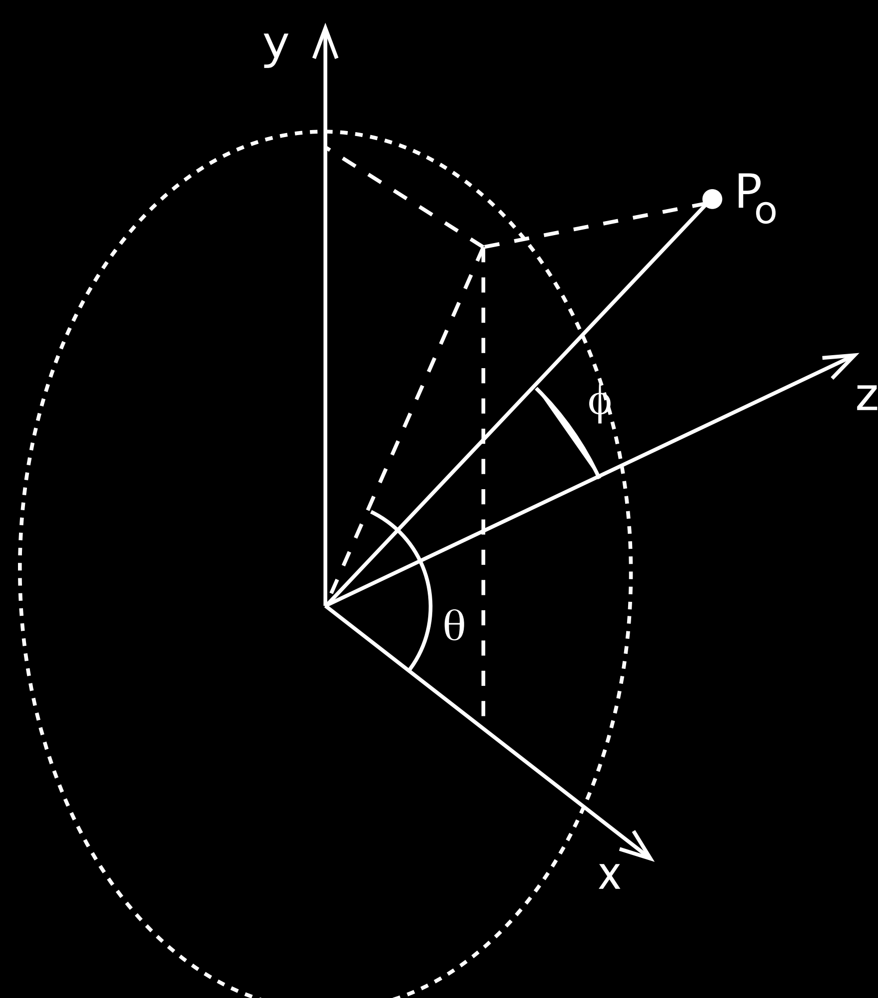
$$P_r = (R \sin(\phi) \cos(\theta) \pm (E/2) \sin(\theta_2),\ R \sin(\phi) \sin(\theta),\ \cos(\phi) \pm (E/2) \sin(\theta_2))$$

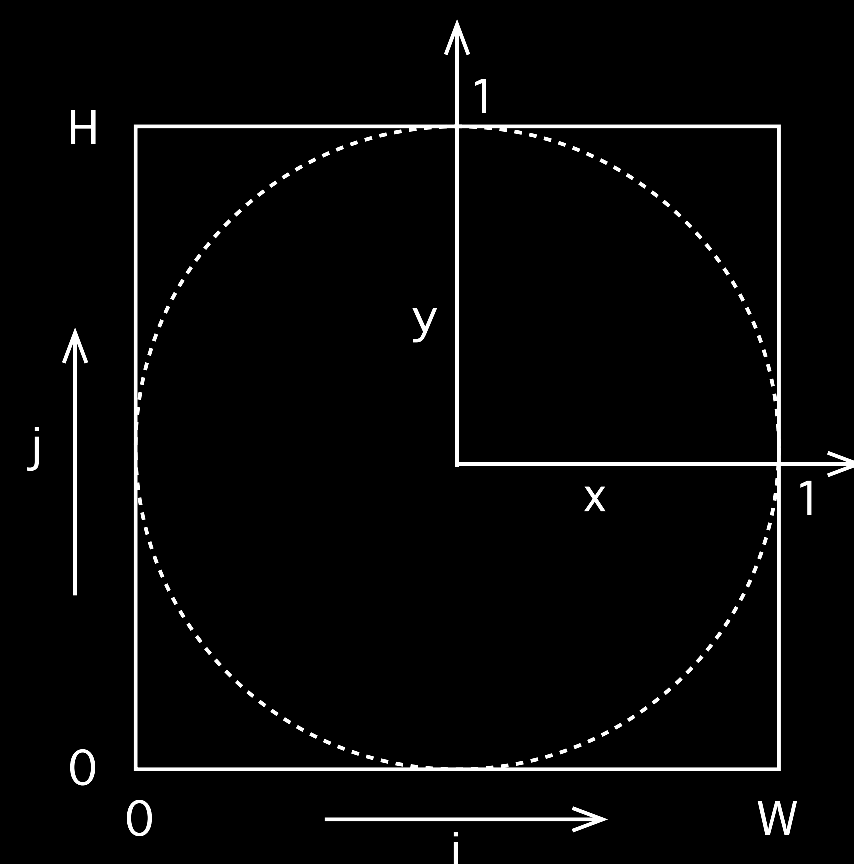
Where θ_2 is the angle to the x axis of the projection of pixel position ray P_o onto the x-z plane, namely

$$\theta_2 = \text{atan}(z_o/x_o)$$

The camera position is now dependent on the fisheye pixel position and given by

$$P_c = (\pm E/2 \sin(\theta_2),\ 0,\ \pm E/2 \cos(\theta_2))$$



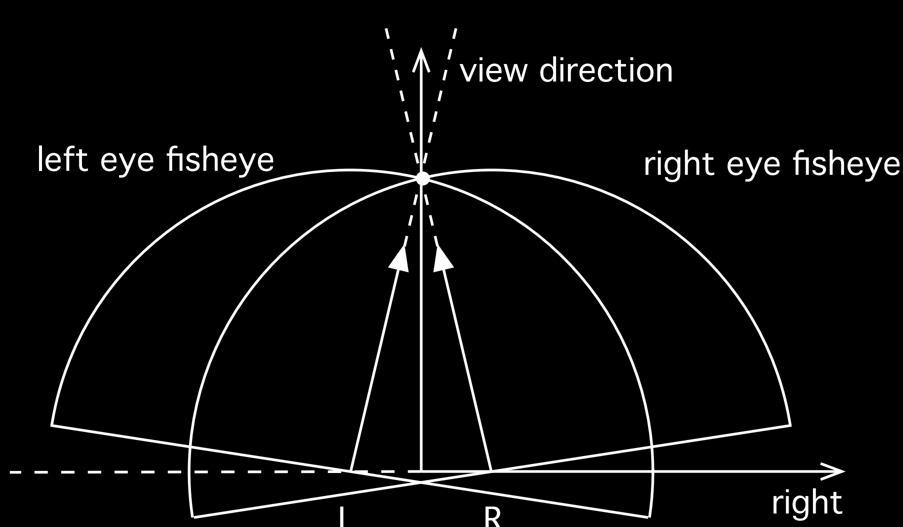


Omnidirectional fisheye generation

- Raytracing: The ideal approach is where one can specify where rays are traced from and what direction they head in. For example, proof of concept was implemented in PovRay with a new camera type.
- Realtime (eg: OpenGL) is best performed with a vertex shader. Note that this requires a geometry tessellation.
- Photographically: By stitching together multiple slit fisheye lens images. That is, using lots of a narrow horizontal strips from a fisheye lens.
- Film footage: ?!

Toe in offset fisheye pair

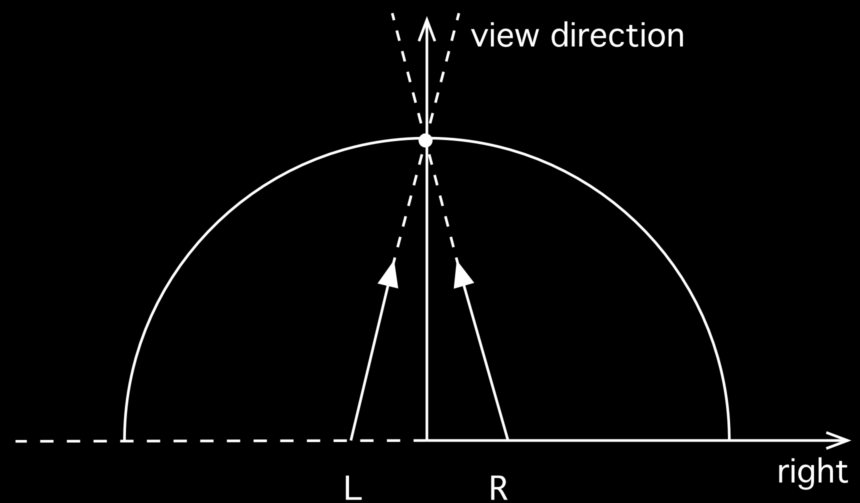
- Toe in fisheyes follow from the (incorrect) toe-in stereo sometimes used for standard projections.
- Note parallax errors at "A".
- Over-rendering can be performed to solve the loss of image on the sides.



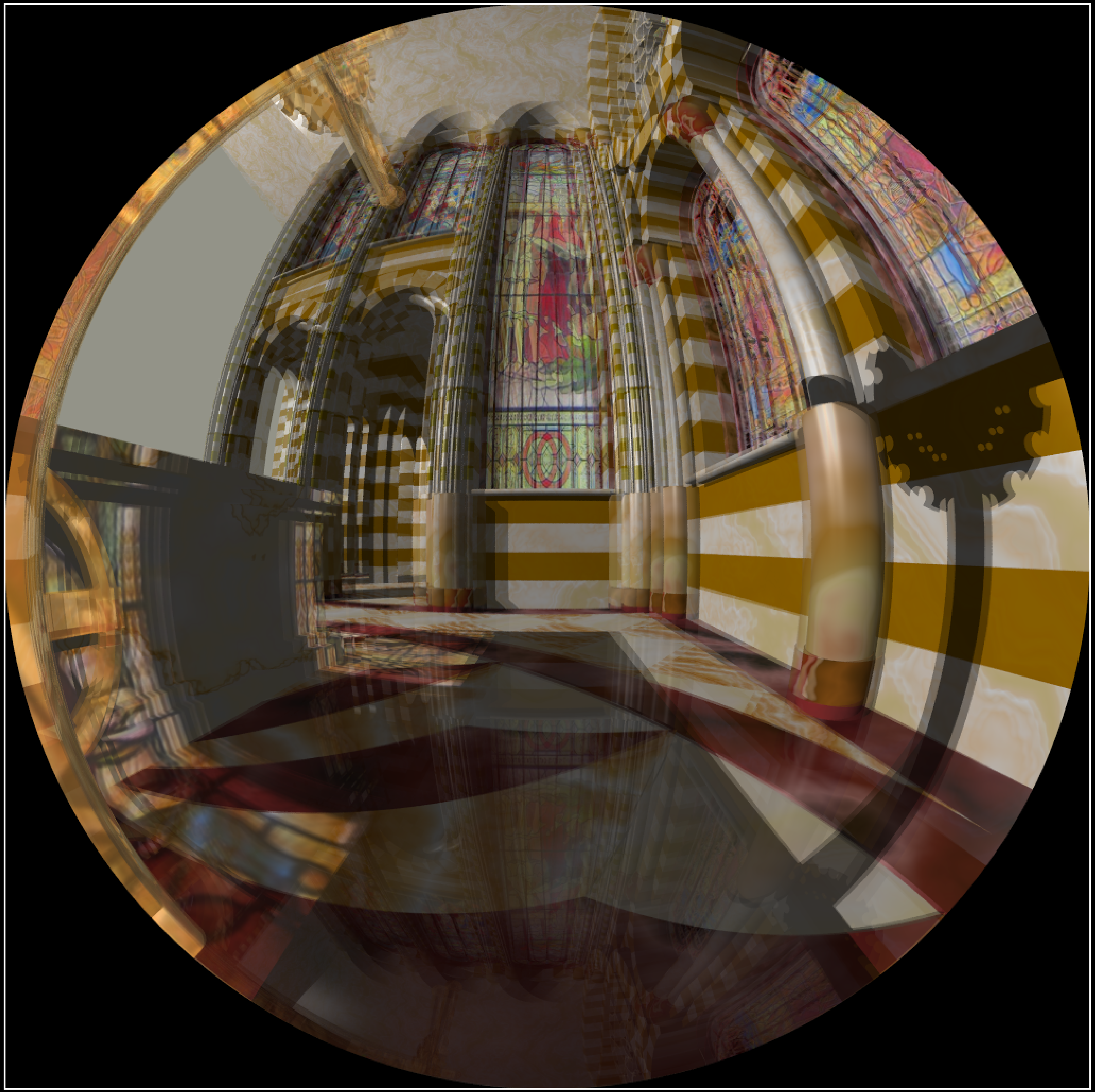
Redentore model courtesy Nathan O'Brien

Offaxis fisheye pair

- In an offset fisheye the point from which the rays are emitted is not at the center of the hemisphere.
- Traditionally used to provide fisheye views for a user also not located at the center of the hemisphere.
- Note vertical parallax and scaling errors at "B".



Omnidirectional fisheye

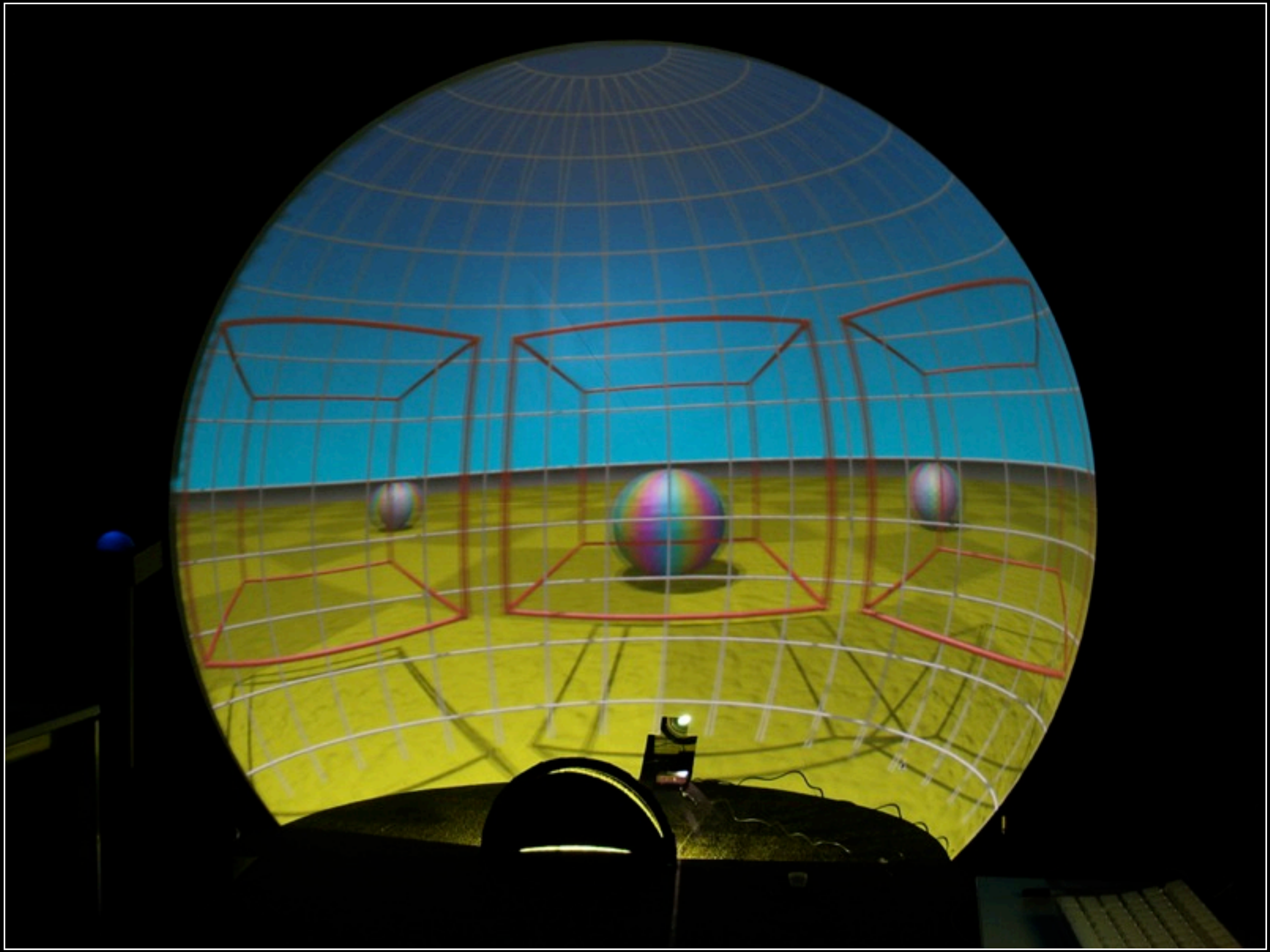


Optimal omnidirectional stereoscopic fisheye pair.

Results in the iDome

Synthetic omnidirectional stereoscopic pairs (PovRay)

Test pattern



Placing objects are known distances and range of positions

Photographic example

Angkor Wat, Courtesy Peter Murphy

Photographic example

Sydney town hall, courtesy Peter Murphy

Future work

- Significant impediment is affordable projection hardware.
  120Hz frame sequential HD (1920x1080) projectors are at the upper end of the price scale.

- Investigate tiled projector solutions ... lower cost projectors but more of them, and a more complicated software model to deal with edgeblending and genlock.

Questions?

Further reading by the author

- Using a spherical mirror for projection into immersive environments.
  http://local.wasp.uwa.edu.au/~pbourke/papers/graphite2005/
  Graphite (ACM Siggraph), Dunedin Nov/Dec 2005.
  Proceedings of the 3rd international conference on Computer graphics and interactive techniques in Australasia and South East Asia. pp 281-284.

- Synthetic Stereoscopic Panoramic Images
  http://local.wasp.uwa.edu.au/~pbourke/papers/vsmm2006/
  VSMM (Virtual Systems and MultiMedia) 2006, Xi'an
  Lecture Notes in Computer Science (LNCS), Springer,
  ISBM 978-3-540-46304-7, Volume 4270/2006, pp 147-155

- Worshop: Stereoscopy, Theory and Practice.
  http://local.wasp.uwa.edu.au/~pbourke/papers/vsmm2007/
  VSMM (Virtual Systems and MultiMedia) 2007, Brisbane.