Apple technology powering displays that engage the human visual system.

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The early computer display mimicked the printed page, black type on white paper became green phosphor on a dark screen. Since then the main advances have been to increase resolution, improve the colour fidelity, and increase the refresh rate. The flat two dimensional screen is still the norm even though our visual system is capable of accepting and appreciating much richer visual stimuli. A number of public outreach, visualisation, and science education suppliers have for some time now been using Apple Mac computers to present stereoscopic images that take advantage of the fact that we have two eyes which, if presented with correctly constructed images, will give the same strong sense of depth we experience when viewing the world around us. The stereoscopic content can be created at interactive real time rates using OpenGL and stereoscopic movies can be viewed using a custom movie player that has been developed locally and is based upon the QuickTime API.

Another characteristic of our visual system is a wide field of view, wide compared to the 20 or 30 degrees normally achieved with current flat screen displays and typical viewing distances. While a wider field of view can be achieved by tiling a number of displays, when viewing a virtual 3 dimensional environment the artifacts inherent in the flat sections limits the sense of immersion possible. A projection geometry that overcomes this is a hemisphere that not only fills the horizontal field of view but also the vertical field of view. Figure 1 shows one such environment, namely an inflatable dome that is used as a portable planetarium. Figure 2 shows another alternative design for immersive virtual reality applications. The challenge is how to project into such a surface without the high cost of the solutions currently on the market, namely multiple projectors or a single projector with a fisheye lens.

It can readily be appreciated that if a data projector is pointed towards a convex mirror, in this case a spherical mirror, then light can be scattered over a wide angle, see figure 3. Projecting onto a surface that wraps around the observer obviously requires that the image contain all the visual information in all possible directions. This is not the case with a standard perspective projection, which typically has visual information for only a relatively small angular view. The most common image format for wide-angle projection is a fisheye image, it contains all the visual information required for a hemispherical display, see figure 4.

If a fisheye image is reflected off a spherical mirror the result will appear very distorted on the hemispherical surface. The trick is to distort (warp) the fisheye image so that the final image on the dome, after it has been reflected off the mirror, appears natural and undistorted, an example of the warping for required for a spherical mirror in a planetarium dome is shown in figure 5.

The technical details on how to compute the warping required will not be discussed here but the approach taken is to model the geometry of the projector, mirror, and hemisphere. The information required for the warping can be determined by simulation, casting rays from a virtual projector through points in the image plane, reflecting the rays off the mirror, and finally calculating the position at which they strike the hemisphere. The description of the warping is encapsulated as a 2 dimensional mesh, each node of the mesh has appropriate texture coordinates such that if the fisheye image is applied to the mesh as a texture, the result is a correctly warped image.

With the release of QuickTime 7, the Quartz engine, and Mac OS-X 10.4 it is possible to perform this warping on the fly and in real time (30fps for full dome movies). A custom QuickTime movie player has been written that plays a QuickTime encoded movie consisting of fisheye frames. It intercepts the QuickTime pipeline so that the frames are rendered as textures on an OpenGL mesh defined with the appropriate texture coordinates to achieve the desired image warp. Before this capability was available in QuickTime it was necessary to prewarp the fisheye movie frames. The problem with prewarping is that multiple movies need to be created for each different projection configuration. With the on-the-fly warping the only difference between environments is the warping mesh read by the custom QuickTime player, the fisheye QuickTime movie doesn't change. It is possible to derive the appropriate warping mesh for other projection geometries besides hemispherical surfaces, for example the 3 walls and ceiling of a rectangular room. The correctly calculated warping mesh will ensure that the projected imagery looks normal and not distorted by the corners in the room.

At XGA projector resolution (1024x768), the fisheye movies are typically 1200 pixels square, these can be played back with the warping applied using a current 12inch Powerbook, small playback hardware is important for portable operations. For larger or fixed planetarium domes the recommended projector resolution is SXGA+ (1400x1050 pixels). In this case the fisheye movies need to be at least 1500 pixels square, playback of these movies used to require a G5 style machine but is now also possible using the Intel MacBook Pro laptops. Because of the tight integration between QuickTime 7 and OpenGL, for all practical purposes there is no penalty between playing the movie normally and playing it with the warping in place.

QuickTime and other integrated technologies in Mac OS-X have played a key role in the implementation of both the stereoscopic and planetarium presentation systems developed by the author. The projection technology discussed here is an entirely new solution to projection into many immersive environments. It is being driven by Apple hardware, OS-X and QuickTime and is currently being used for public education in astronomy using portable inflatable planetariums.

Further reading

[1] Selection of stereoscopic displays by the author.
http://local.wasp.uwa.edu.au/~pbourke/stereographics/installations/

[2] Details on deriving the warping mesh.
http://local.wasp.uwa.edu.au/~pbourke/papers/graphite2005/

[3] Alternative projection geometries
http://local.wasp.uwa.edu.au/~pbourke/projections/mirrorbox/
http://local.wasp.uwa.edu.au/~pbourke/projection/uprightdome/

Figure 1. Inflatable dome currently being used to present educational astronomy movies.

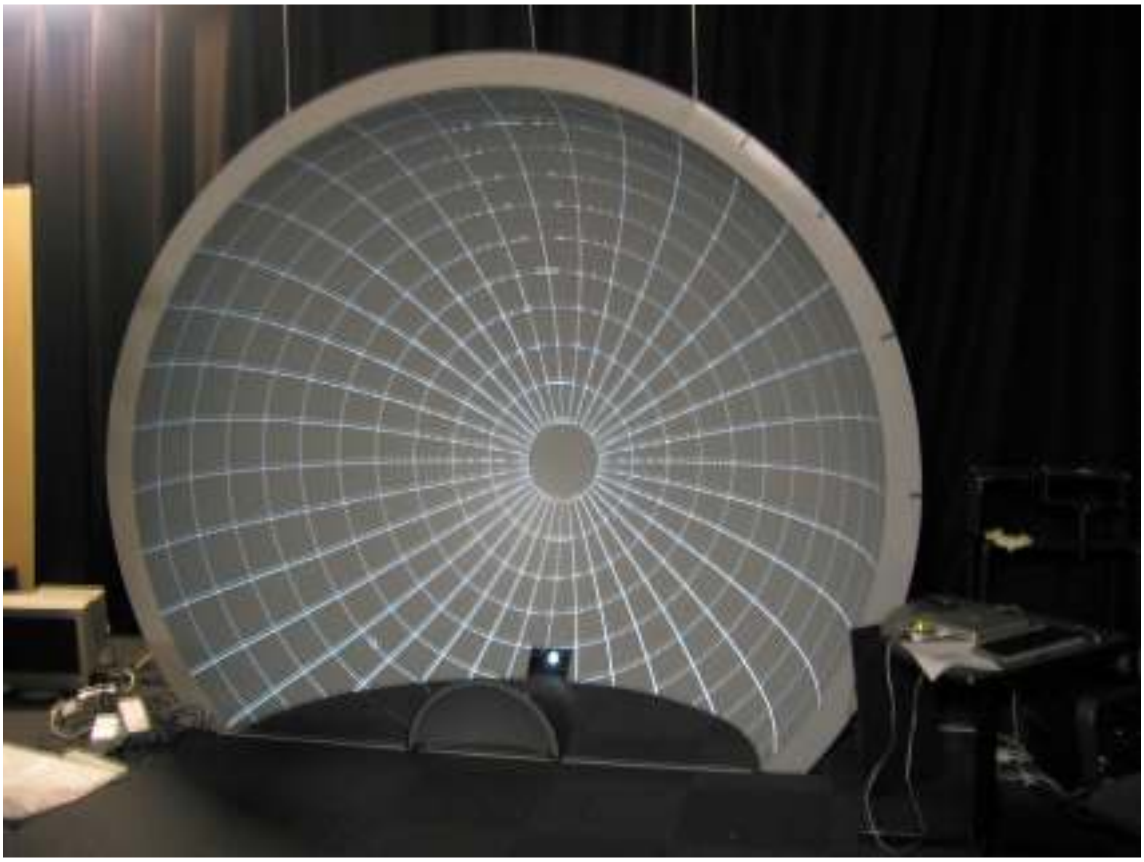

Figure 2. Upright dome configuration for immersive environments.

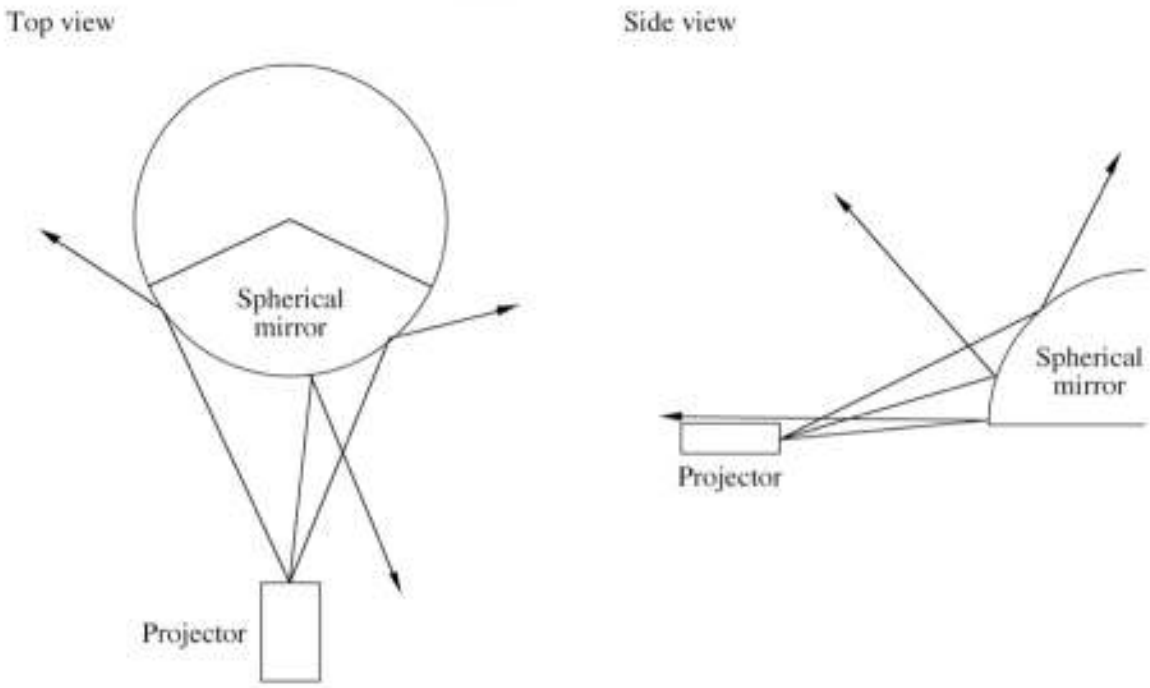

Figure 3. Scattering of light from a data projector through a wide angle by reflecting it off a spherical mirror surface. The mirror is typically located near the rim of the hemispherical dome.

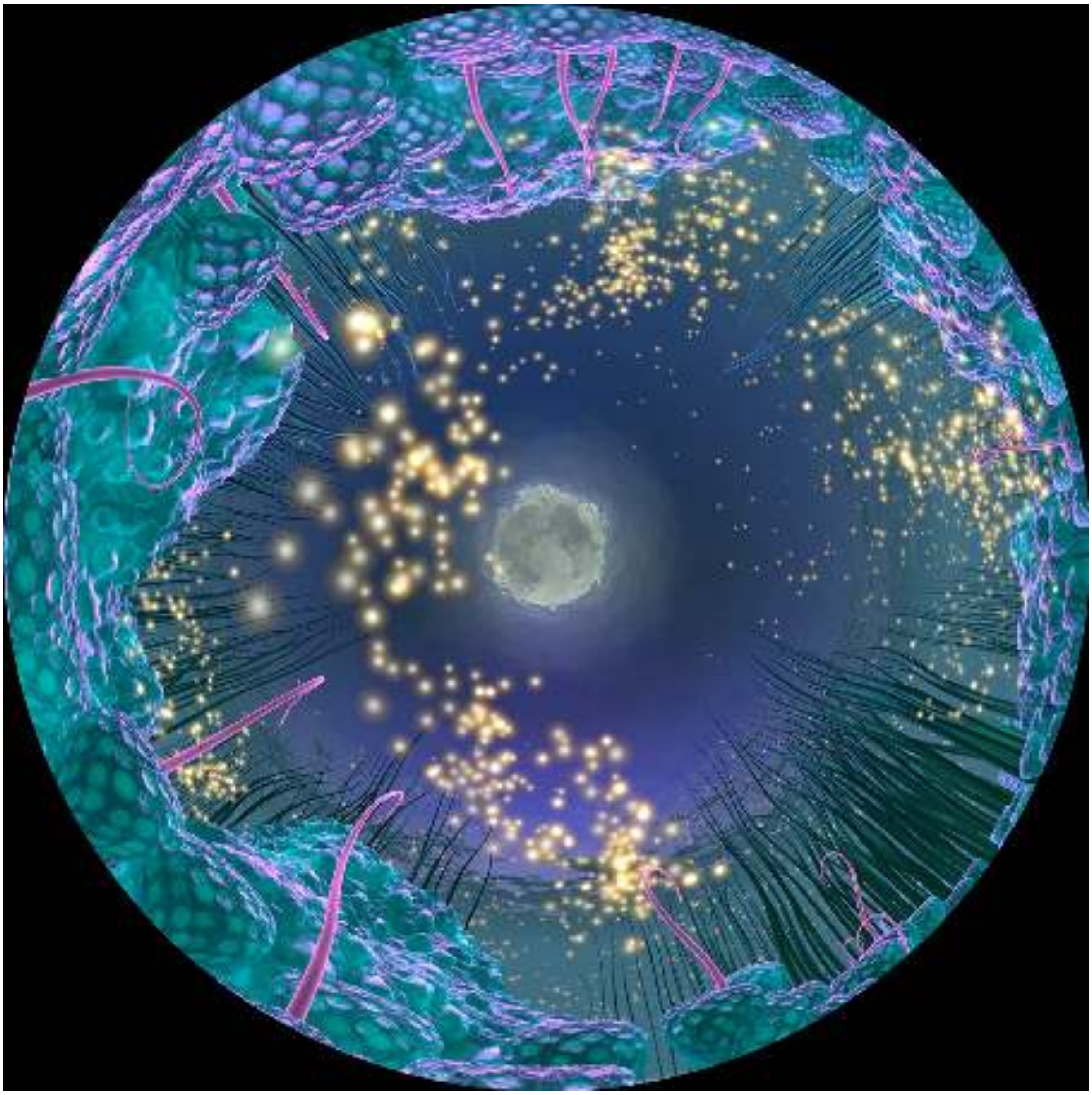

Figure 4. Fisheye image, one frame of a movie that contains visual information for the whole hemispherical surface. Single frame from full dome movie called “Moonlight”, courtesy of Andrew Quinn.

Figure 5. Warped version of the same frame as figure 4. Note the intensity correction for the variable path length of the light from projector to dome.