Visualization on Spherical Displays: Challenges and Opportunities

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ABSTRACT

Spherical displays offer unique characteristics that can enhance perception and provide a natural environment for geo-visualization. Recently, digital artists have begun using the curvature of these displays to create art that works with the medium. These displays are mainly used for outreach and education in public spaces such as museums and focus exhibits where researchers, journalists and artists can have a far-reaching outlet for data, information and art, dissemination and presentation. The form factor of the display is well-liked and understood by the general masses. In this paper, we focus primarily on the challenges and opportunities of the spherical display format in public and educational venues. We present critical design considerations for works created for a spherical display and provide examples from different domains.

Index Terms: J.2 [Computer Applications]: Physical Sciences and Engineering—Earth and atmospheric sciences; J.5 [Computer Applications]: Arts and Humanities—Fine Arts

1 INTRODUCTION

Globes reflect the actual shape of our world, agreeing with the goal of cartographers to create content which resembles reality as closely as possible. When compared to flat maps, globes are superior for showing the undistorted shapes, relative positions, and relative sizes of land masses and bodies of water. Globes also provide more accurate information about the distances and directions between locations. Disadvantages of globes when compared to maps are their limited size and relatively low resolution, difficulty in transporting, and, perhaps most importantly, the restriction of viewing to at most half of the surface at any given time. Nonetheless, in this age of ubiquitous online digital mapping, the globe still holds a unique fascination in the eyes and imaginations of viewers.

The first known globe still in existence was created in 1492 by German navigator Martin Behaim (ironically, this globe became outdated later that very year by Columbus' discovery of America) [8]. More than 500 years later, the introduction of small digital projectors and LED panels have enabled the creation of digital globes and spherical displays that permit the presentation of a wide range of static, animated, and dynamically updated information visualizations and digital content. Today, spherical displays can be found in museums and science exhibits, among others.

Another subject of interest is the role that aesthetics and storytelling play when creating visualizations for spherical displays. The conception, purpose, and nature of spherical displays mandates a close look at aesthetics, both in creating geo-representational and abstract artistic visualizations. Similarly, the unique characteristics of the displays afford interesting usage and interaction scenarios that go beyond flat displays when creating narrative.

This paper discusses the challenges and opportunities afforded by digital spherical displays in public and educational venues. This work is related to projects with the National Oceanic and Atmospheric Administration's Science On a Sphere (SOS) projector-based system. Our goals with this paper are:

- to provide a survey of spherical display uses and benefits
- to describe the technical methods and design considerations important for spherical displays, and
- to present successful examples of visualizations and artworks based on spherical displays.

2 RELATED WORK

Visualization on spherical displays intersects with work in the areas of visualization, public information displays, aesthetics and storytelling, among others. In this section, work in these fields is briefly presented.

2.1 Visualization

Two-dimensional renders of three-dimensional datasets can be enhanced and new insights gained by viewing this information in a natural three-dimensional environment [4]. Research suggests that realistic three-dimensional visualization may be understood more intuitively than traditional maps [17]. Hruby et al. [10] propose the term ”*tactile hyperglobes*” which ”result from a visualization of the digital image on a material globe body in real space.” The hyperglobe is described as a potential tool for effectively relaying complex scientific concepts to the general population. The display can clearly link regional phenomena to a global system and help bridge a communication gap between discoveries and human recognition.

2.2 Public Information Displays

Modern screen-based information visualization, long used by researchers and in the work place, has burst onto the public scene in the last decade with the proliferation of handheld devices and integration via social networking applications as well as deployment of displays in many settings. “Urban screens” are being found in more and more spaces ranging from museums to shopping malls to airports, and their form factor varies from single flat-screens to high resolution tiled walls to spherical screens. The availability of tailored visualizations in these spaces has led to an emphasis on aesthetics as a method to motivate people to invest time in the display as well as incentive to explore it [20].

2.3 Aesthetics and Storytelling

When looking at prior evaluations of spherical displays, a common thread appears: the mode of display is not the issue, instead the method of presentation of any given topic is important. Whether flat or spherical, aesthetics and storytelling play an increasingly important role in visualization, especially when the target audience is the general public.

Experience with the Science On a Sphere system has shown that the spherical shape provokes the inherent interest of viewers while

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still providing the necessary environment for accurate and informational geo-visualizations. As an exhibit, it was observed that visitors stayed at SOS installations for longer amounts of time than similar exhibits. When asked about the sphere, visitors mentioned that the display was innovative, an aesthetic experience, and a versatile education tool [16].

Riedl and Wintner relate storyboards to the process and focus on the connection between interactive digital storytelling and spherical geo-animations as a more emotional way of telling a "global story" [18]. When creating visualizations for the SOS that are georeferent, it is important to create a narrative. Adhering to a theme or a target audience results in better reception and promotes interpretation.

2.4 Perspective and Perception

Artist and journalist Ingo Günther believes that a spherical display affords a new perspective; it is an object with which the artist, journalist, or scientist can create another version of the world to see [9]. Leonardo Da Vinci considered classical perspective projection (planar projection) to be "artificial," and what he denominated "Natural Perspective" to be the best projection that produces the image as beheld by the eye. ("Natural Perspective" is simply the projection of the environment onto a spherical surface) [14]. However, spheres need not be constrained to this idea of "best projections."

There is a growing body of work on "educational aesthetics," which look to art to explore concepts often associated with science without being constrained by literal representation [5,22]. Campbell stresses that while art often depicts different types of technology (such as watermills, bridges, different kinds of transportation) that art itself is impacted and instructed by science and technology. M.C. Escher's "Hand with Reflecting Sphere" is one such piece of art that plays with optics, reflection, representation, and expectation that translates well to experimentation on a sphere. At Indiana University, a group of students in a digital photography course were asked to take two self-portraits, one inside and one outside, with architectural lines and in right angle spaces for projection on the SOS without warping. The idea was to take these "inside-out" portraits and distort them further, playing off of Escher's piece and the now ubiquitous "selfie."

3 TECHNOLOGY

The following section gives an overview of hardware and software specifications for spherical displays.

3.1 Spherical Displays

Spherical displays are commonly produced with projector-driven video output. Projectors offer the advantages of seamless images and flexibility regarding sphere size and mobility. Commercially available spheres come in sizes ranging from 40 cm to 3 m and can be driven by one or several projectors.

In 1995, Alexander MacDonald came up with the concept of Science On A Sphere. SOS is a large visualization system that uses computers and four video projectors to display animated data onto the outside of a sphere. This system was patented in 2005. There are over 106 SOS installations worldwide with a robust user community that benefits from centralized support from the National Oceanic and Atmospheric Administration (NOAA) and over 400 contributed or NOAA-generated data sets [1]. Internally-projected spheres are also commercially available. The Ominisphere and PufferSphere are two examples of these displays. The OmniSphere is an internally-projected acrylic sphere using one or two projectors and special internal mirrors; this system was patented in 2002 [13]. PufferSphere displays come in various sizes and deliver 360 video via special lenses. The display itself can be a large format inflatable or a smaller high-brightness "HardBall" [5].

In addition to SOS and projector-driven displays, the National Museum of Emerging Science and Innovation in Tokyo, Japan has an OLED-driven spherical display named the "Geo-Cosmos" globe. This display has over ten thousand OLED panels and can support a resolution of more than 10 million pixels. It is both brighter and capable of a much higher resolution than a projector-based display, but cannot display a truly seamless image due to the individual OLED displays. Along with Indiana University's SOS, the Geo-Cosmos display has featured digitized works from Ingo Günther's Worldprocessor project [9].

Indiana University's installation of Science On a Sphere consists of a 1.7-meter diameter opaque sphere made out of carbon fiber. The lightweight construction of the display allows for it to be suspended by wires to provide a "floating" effect. Science On a Sphere installations typically display visualizations at a 2K resolution, and the display is most often located in public spaces as a featured exhibit.

3.2 Display Software

The software that drives spherical displays can differ greatly depending on the display's manufacturer and the hardware capabilities. In most cases, the display software does no direct visualization, but simply plays back pre-rendered visualization media (images, image sequences, or movies) while performing the necessary warping, overlapping, blending, and synchronization operations necessary to match the display's projector or panel configuration. In some installations, viewers are allowed to select the media they wish to view; in others, viewers control the virtual orientation of the sphere, the playback speed, or visibility of specific layers or annotations. Spherical displays, such as the PufferSphere [5] and those created by Benko et al. [3], support touch interaction on the surface of the sphere. This dynamic interface changes the software requirements and how media is created for this device. In contrast, Science On a Sphere provides basic control interactions for selection, orientation, and playback control through an iPad application or with a Wii remote.

Because most spherical displays systems play back prerecorded media, content developers are free to create that media with the 2D or 3D visualization package or media creation tool best suited to their needs. The only general requirement is the need to output media at a recommended resolution using a specific projection model (e.g., in the case of SOS, 2K resolution in an equirectangular projection.) This flexibility enables a great variety of content encompassing photography, videography, satellite imagery, simulation visualizations, information visualizations, CGI representations, hand-drawn imagery, and various combinations of the above. While this resulting variability in style, content, and aesthetics can be interesting and engaging for viewers, it can also create confusion and inconsistencies in terms of representation, interpretation, quality, accuracy, and overall effectiveness. It is our hope that the community of display sites and content developers can adopt a more consistent set of techniques, representations, and best practices to increase literacy and effectiveness among viewers without suppressing creativity and innovation.

3.3 Physical Location and Navigation

Physical navigation of a spherical display is influenced heavily by visual acuity and the location. With a spherical display, a viewer will not be able to see half of the imagery at any given time. Walking around the globe becomes an instinctual way of navigating, and provides natural relative size and distance references for the world, although virtual rotation of a visualization can bring the entire sphere into view from a stationary viewpoint. The location of the display can greatly impact the effectiveness of physical navigation. SOS displays acting as featured exhibits can cater the location and height for the needs of the viewer. This typically calls for having the equator of sphere at adult eye level, and having ample space to walk around the display. At Indiana University, the display is located at a greater height (equator at 12 feet above floor level) in a open, multi-story public atrium. Displays in similar locations create many viewpoints, both above and below the sphere, but lack the same level of intimacy a viewer might experience with a smaller and lower exhibit space.

The form factor of the display impacts the type of physical navigation done by the viewer. Spherical displays offer an unobstructed 360 degree field of view to all viewers, enabling them to explore different perspectives of the display data by physically moving around the display [3]. The perceptual range and the capacity of the viewer must be also be taken into account.

Spherical displays are rarely viewed by a single individual. The spherical shape combined with the environments they are often placed in promote the idea of a shared display. A notable social advantage of spherical displays over flat displays is that viewers can naturally see and interact with each other as they look across or around the sphere. Physical navigation becomes increasingly important so viewers can control their own exploration of the content. This can complicate interfaced navigation. As an individual changing content, pausing/playing animations, or digitally rotating the data, could be disruptive to other viewers. Forlines et al. conclude that when a team is working closely together, even on a shared display, interactions or changes caused by an individual are expected and non-disruptive [7]. This is observed with spherical displays used for group demonstrations or presentations, where a designated individual or docent will control and explain the content.

4 DEVELOPING VISUALIZATIONS FOR SPHERICAL DISPLAYS

The form factor of spherical displays is well understood by the general masses, particularly when coupled to geospatial datasets. Therefore, geo-visualization is a natural fit for this type of display and it is a major focus for this work. In this section, we describe some of the general considerations for developing visualizations for this form factor and for geospatial based visualizations. This does not mean that geo-referenced work lack aesthetics or artistic considerations. Instead, they are essential for effective visualization and impactful storytelling that can educate and surprise viewers about a broad range of world events and can relay narratives in unexpected ways. Non-georeferent work is also engaging and instructive. In Section 5, the work of digital artists and information designers will be profiled as an alternate method of using the SOS in a non georeferent manner.

As described in section 2.3, almost any 2D or 3D visualization, animation, or media design software can be used to create content for playback on spherical displays. In light of this vast flexibility, it is useful for content developers to be aware of spherical design considerations, common geometric and layout challenges, and established and effective solutions.

4.1 General Design Considerations

For visualizations on spherical displays, it is important to consider how the visualization adapts to the display's affordances and limitations. The designer must take into account all the different methods with which visualizations can be structured for this geometry. The form factor of the display mandates closer attention to information visualization techniques that account for data occlusion, glyph and annotation distortion, limited navigation, and display in public spaces.

Since the spherical display typically functions as an overview or high-level object in a public space, visualizations should focus on communicating a high-level message. Information is best distilled to make a more clear representation of the underlying data. Information or data occultation due to the form factor of the display can be overcome by either communicating the intended message on just one viewpoint while hiding other data or by displaying the data at equally-spaced intervals on the sphere, preserving the message for viewers from all angles.

Other considerations to take into account are brightness of the display, location (eye-height or suspended from ceiling for example) and methods of interactivity.

4.2 Layout Displacement

Due to technological or installation limitation, many spherical display technologies have blank spots below approximately -80 and/or above approximately 80 degrees of latitude. Additionally, for political and social mapping, there is a larger degree of country and population clustering at higher latitudes than at lower latitudes, particularly over Europe. In order to overcome crowded data representation over regions of high data clustering, a geometric displacement technique can be used, in which data is sorted based on a centroid over the clustered area and displaced with respect to a geometric figure, such as an arc. Conversely, the data can be sorted based on only the latitude and displaced based on a geometric figure. Figure 1 shows a before and after visualization after implementing the data sort. It should be noted that areas of dense information might be better represented via color only; adding numeric or textual clarification might still be considered information overload. Alternatively, this information could be displaced to a legend elsewhere on the sphere. (See Figure 10 and Figure 11 for other solutions to this type of information density.)

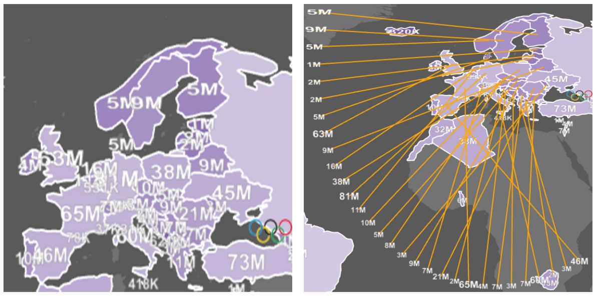

(a) Before displacement (b) After displacement

Figure 1: Geometric Displacement Example

The later technique is not as visually clean, but it is straightforward to implement. The position of a particle along a circular path is:

$$x_D = Rcos(\delta\theta) \tag{1}$$

$$y_D = Rsin(\delta\theta) \tag{2}$$

where R is the radius of the displacement arc, x_D and y_D are the x and y coordinates for the position of the glyph, $\delta\theta$ is the angle along the arc, as shown in Figure 2.

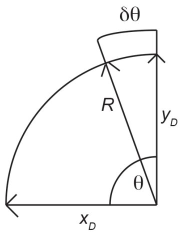


Figure 2: Diagram for layout displacement.

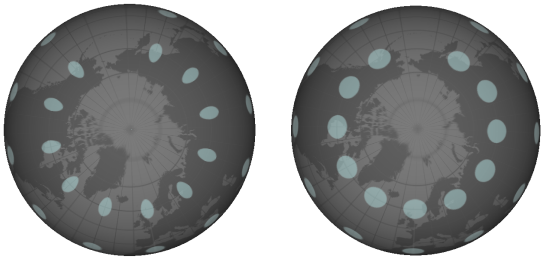
4.3 Distortion Techniques

When putting georeferent data onto a spherical medium, it is necessary to correct for the distortion that occurs when wrapping a 2D image to the 3D surface. Equirectangular projection solves this problem. An equirectangular projection is commonly referred to as a simple latitude and longitude grid, where the image is a standard cartographic map projection that is twice as wide as it is tall (2:1 ratio). For a sphere, it is important that the data fill the entire image space, otherwise borders or extra space around the edges will create a seam when projecting the image. The equation for translating spherical coordinates to equirectangular projection are shown in Equations 3 and 4, where λ and ϕ are latitude and longitude and where ϕ_1 are the standard parallels (north and south of the equator), which for our purposes will be zero. (This is also known as Plate Carrée projection.)

$$x = \lambda cos\phi_1 \tag{3}$$

$$y = \phi \tag{4}$$

The most noticeable distortion in these maps is the horizontal stretching that occurs as one approaches the poles from the equators. This culminates in the poles (a single point) being stretched to the whole width of the map (Figure 3). For purposes of displaying glyphs, annotations and legends on the spherical display, it is important to take into account this distortion. It was found that there are several methods that can be used to calculate the distortion and different terminology. For our purposes, we will briefly review the Tissot indicatrix method used in mapping projections. This technique will correctly warp or distort the image for texture mapping the sphere. Other tools to distort images include the FullDome plugin software for Adobe After Effects, texture baking using 3D rendering software such as CINEMA 4D and panorama photo stitching software such as Hugin.



(a) Before distortion (b) After distortion

Figure 3: Distortion technique example

4.3.1 Tissot Indicatrix

In 1859 and 1881, Nicolas Auguste Tissot published a classic analysis of the distortion which occurs on a map projection [19]. The intersection of any two lines on the Earth is represented on the flat map with an intersection at the same or a different angle. The greatest deviation from the correct angle is called ω, the maximum angular deformation. Tissot showed this relationship graphically with a special ellipse of distortion called an indicatrix. The indicatrix is an infinitely small circle on the Earth which projects an infinitely small, but perfect, ellipse on any map projection. This is a useful tool when working with different map projections to show deformations.

For our purpose, we have limited this discussion to the formulas as applied to a regular cylindrical projection of the sphere in which scale is solely a function of the latitude. Since this calculation assumes an infinitely small ellipse, the scale is accurate up to 10 to 100 meters in size [19]. If the size of the ellipse is larger, the scale becomes a function of latitude and size. In our implementation we use texture quads, where we scale the vertices of the quad at every pixel. The texture corresponds to the graphic we want to show on the map.

The Tissot ellipse has a major axis and minor axis which are directly related to the scale distortion and to the maximum angular deformation. For our case, the maximum angular deformation is defined as:

$$sin\frac{\omega}{2} = \frac{|cos\phi - 1|}{cos\phi + 1} \tag{5}$$

If a is the major axis and b is the minor axis of the ellipse, and b remains unchanged in an equirectangular projection, then the distortion along x (or along the major axis of the ellipse), is defined to be:

$$a = \frac{-b(sin\omega/2 + 1)}{sin\omega/2 - 1} \tag{6}$$

In our implementation $b = 1$, and thus the x vertices of the quad are scaled by a or by a function of a and the size of the quad. Figure 4, shows a Tissot's indicatrix for a equirectangular projection.

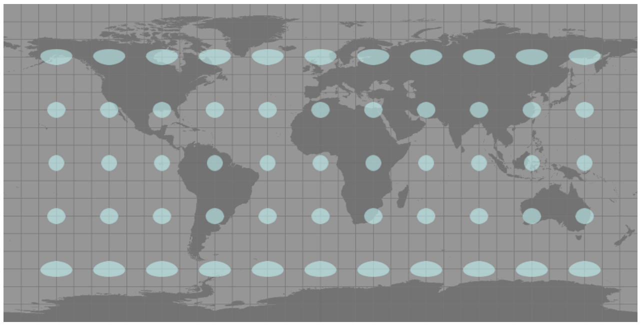


Figure 4: Tissot Indicatrix

The previous algorithm was implemented using the Processing programming language and is available for download from the author's GitHub page [21].

4.4 Visual Encodings

4.4.1 Edges

Special considerations have to be taken when creating map-based network diagrams in which the international date line has to be taken into account. Geographic Information Systems take into account this limitation. However, if the visualization is created with other software, the designer should be aware and incorporate this limitation into the design process. For edges in geographic connections, it is recommended to use great circles, also known as Riemannian circles. The minor arc of a great circle is the shortest distance between two points, and it is typically used in nautical and flight routes. Figure 5 shows a visualization created for Indiana University's Science On a Sphere, in which a great circle routine was used. Note that the 2D arcs will become straight lines when projected onto the sphere.

4.4.2 Glyphs and Text

Glyphs can be used for data aggregation and representation, particularly over areas of dense data-clustering. Glyphs should be designed keeping in mind the public nature of the spherical displays discussed in this paper. How much viewers are able to distill information is largely dependent on their general visual literacy, their domain knowledge, and their ability to detect the visual cues that are purposefully built on the map by the map maker [17]. Text and

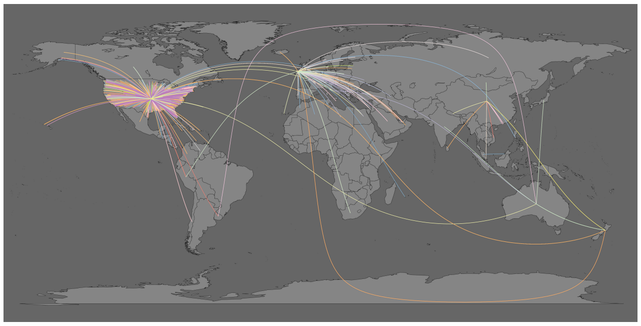


Figure 5: Network visualization using great circles

numbers can function in a similar way, serving as "glyphs" that require much less interpretation on the part of the viewer.

In the WorldProcessor work by Günther, the goal of the artist is to allow the audience to fill in the gaps and come with their own understanding of the dataset, while in traditional weather visualizations, for example, the goal is to present the audience with the complete data, presenting facts and trying to minimize subjective representations of the data.

4.4.3 Choropleth and Cartogram Maps

A choropleth map is a thematic map in which areas are shaded or patterned in proportion to the measurement of the statistical variable being displayed on the map, such as population density or per-capita income. Choropleths are useful for spotting regions of similarity as well as outliers. However, they can make it difficult for viewers to extract values directly from the map, and can suffer from an exaggeration effect of larger regions over smaller ones. Careful selection of a discrete set of colors and multiple, easy to read legends around the display can address these drawbacks. There are multiple software packages that can be used to construct choropleths, including R, ArcGIS, Tableau, and Indiemapper.

A cartogram is another form of thematic map which scales the sizes of regions based on statistical values. One type of cartogram maintains connectivity between regions and performs a fisheye-like expansion or contraction, resulting in countries that appear "puffed up" or "deflated". The other variation maintains the shape of countries but sacrifices connectivity when scaling, creating a "puzzle piece" effect. One major problem with cartograms is that they can destroy the recognizability of the visual landmarks that viewers rely on to mentally navigate the globe. We have found that a short animation from the normal, unscaled map to the distorted, scaled map helps users to better understand these representations. An unaddressable problem with cartograms is that they cannot be used with other data layers as the boundaries no longer align.

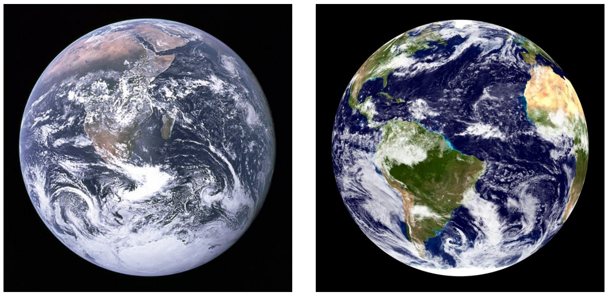
4.4.4 Temporal Data

Many interesting and important global phenomena emerge over time (e.g., climate change). Temporal animations or image sequences are an obvious way to present such data, however, attention to several details can enhance the interpretation by viewers: data encoding ranges should be standardized across all time steps; indicators of overall maximum and minimum values should be visible across all time steps; and visual transitions should be selected so as to maximize comparisons between successive time steps. As always, particular attention should be given to the visual acuity of the viewer.

4.5 Aesthetic Considerations

A substantial aspect of visualization for the masses and in public spaces is the importance given to aesthetics. Three dimensional content not only engages the public by offering an accurate real-world perspective, but plays an important role in communication support [17]. Work by Kosara [12] emphasizes the importance of visualization criticism and the missing link between information visualization and art, and introduces the concepts of *pragmatic visualization*, the technical application of visualization techniques to analyze the data, and *artistic visualization*, used to communicate a concept, rather than to show data.

Kosara also brings up the notion of the *sublime*, one that is extremely helpful when discussing information visualization from an artistic standpoint. With definitions dating back to antiquity, the *sublime*, is generally understood to apply to that which inspires deep emotion or thought. In Figure 6, the Blue Marble dataset (based on the 2D blue marble image taken by astronauts aboard the Apollo 17 in 1972) is a 3D rendition compositing land and sea from June to September of 2001 and three days worth of cloud data [15]. It allows earthbound humans to view our planet from a completely different perspective, yet one that mimics its place in the universe. Many have commented on the uncanny nature of this familiar picture fully realized on a large three-dimensional surface in great detail.



(a) 1972 NASA Blue Marble (b) 2001 3D NASA Blue Marble

Figure 6: NASA's Evolvling Captures of Earth

4.5.1 Color

With respect to color, work by Endert et al. demonstrated that color made a particularly effective encoding because of the way that it visually aggregates to provide the user with distinctive patterns [6]. Tools like Kuler and ColorBrewer can be used to assist in the design of the color palette. For projection displays, particular attention has to be given to the brightness of the projectors and well as to the natural light in the display's environment. For the SOS system in particular, grey tones, for example, are found to show higher contrast than black. With respect to the installation at Indiana University, the difference in brightness levels were more easily perceived after 20 percent. Anything between zero percent and 15 percent will not be easily distinguishable. The seams where the projector images overlap become increasingly noticeable at higher brightness levels, between 80 percent and 90 percent. Many datasets use light colors, but designers should be aware that the seams will be visible.

4.5.2 Lines and Fonts

Font sizes were tested at both 4K and 2K resolutions using the Arial font. At 4K, the smallest font size recommended is 24 point. Smaller text may be readable, but for visibility purposes it is not recommended. For 2K resolution, it is not recommended to use a font size smaller than 14 point. Line widths were tested with white lines over varying greyscale backgrounds. We tested 1, 2, 3 and 5-pixel width lines. A 1-pixel line was viewable but distorted, therefore a 2-pixel line width or above is recommended.

4.5.3 Inverse Representations

What is *not* shown on a map can be just as important as what *is* shown. For example, rather than visualizing Olympic medals won, it can be more interesting to note which countries have *never* won a medal in any Olympic games (Figure 7). These “inverse representations” detach viewers out of their typical expectations and challenge them to think of issues in complementary ways.

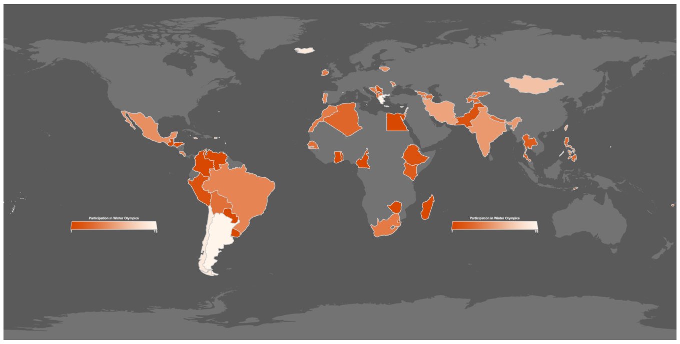


Figure 7: Examples of Inverse Representations: Countries that did not win any medals during 2014 Winter Olympics

4.6 Storytelling Considerations

According to Jobst, if one element among hundreds catches the attention of the viewer because of double or triple coding (e.g. using extraordinary color, shape and sound), there will be a better chance for a long-term effect on information dissemination, since the processing area within the brain that stores information, receives inputs of the same information from different sense organs [11]. Science On a Sphere software supports the use of supplemental text and annotation image overlays to describe each stage in the visualization story. Image sequences and movies can also be coupled with narrated voice-overs. Coupling sound with the visual representation can aid storytelling and visual perception. For the Geo-Cosmos globe, a combination of sound and visual cues are integrated to engage the viewer in a multi-sensorial experience.

4.7 Interaction

Spherical displays offer an unobstructed 360 degree field of view to all users, enabling them to explore different perspectives of the displayed data by physically moving around the display [3]. The natural physical navigation and interaction with the display compliments the public usage of spherical displays. On the other hand, computer interaction is limited to the hardware and software distributed by each commercially available display. Touch-screen displays are, in some cases, coupled with spherical displays along with brushing and linking techniques in order to allow interaction with the viewer. In public spaces where the exhibit is designed for multiple viewers, minimizing this interaction should be part of the visualization design. On the other hand, in educational environments, viewer interaction with the data is an important component of the learning and engagement process. Indiana University has developed two additional interfaces for its SOS to better engage viewers and to leverage its other display technologies.

4.7.1 Multitouch Content Browser with OpenExhibits

The OpenExhibits framework was used to create a multitouch screen application. This application runs on a touch table close to the spherical display, and includes a gallery of unwrapped spherical images or maps (Figure 8). This gallery allows a viewer to categorize the data, see information about the data, and send the data to be viewed onto the sphere. This resource has empowered viewers to interact with the sphere and learn more about the data without any assistance.

Figure 8: Multitouch SOS interface built with OpenExhibits

Figure 9: WorldProcessor globe exhibit (foreground) with X3D sphere emulator on a 50 megapixel tiled wall (background)

4.7.2 Experiencing Content on Other Displays with X3D

An interactive sphere emulator was created using X3D to allow viewing of SOS datasets on non-spherical devices. The tool parses the SOS data files and texture maps the media to the surface of a three-dimensional spherical mesh. This tool has proven useful for use with mobile devices, web delivery, large format ultra-resolution displays, and immersive virtual reality displays. On ultra-resolution displays, this emulator provides a “small multiples” representation of the diversity of data that has been created for spherical displays (Figure 9 background). This is also reminiscent of Günther’s preferred exhibit style for his WorldProcessor installations (Figure 9 foreground).

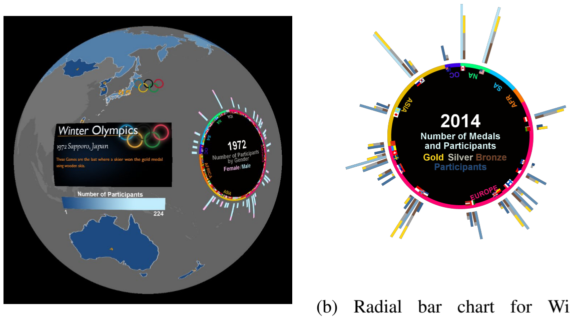
5 EXAMPLES AND DISCUSSION

The following examples illustrate several information visualization and artistic installations designed for spherical displays.

5.1 Mapping the Winter Olympics

Figure 10 shows worldwide participation in the 2014 Winter Olympics. In this visualization, a choropleth map in shades of blue represents the number of athletes sent by each participating country. Yellow labels provide a redundant coding indicating the precise number of the athletes, and the text is scaled in size respectively. A stacked bar chart in a radial layout is located in the Pacific Ocean. It shows the division between male and female participants per country. Within the chart, participating countries are grouped by continent and identified with the country flag. This dataset is an animated time sequence that starts with data from the first official Olympics in 1924, and ends with the 2014 Winter Olympics. Annotation overlays aid with storytelling by providing historical context or an interesting fact for each Games. The circular nature of the bar chart also mimics the Olympics rings and the circular nature of the sphere itself, so that interconnectivity is subtly reinforced.

This was one of three separate data sets that visualize various aspects of the Winter Olympics. The second data set maps the number of medals won by each country in each Games. The third data set presents alternate ways to scale the participation and medal data to achieve a more meaningful comparison across countries, such as looking at medals won per participant, participation as a function of overall country population or wealth (GDP), or medals won based on population, GDP, or both. Although all show different data, the general layout and visual encodings remained consistent across all three data sets. Different primary colors in their choropleth color maps helped reinforce the change in the data to the viewers while facilitating comparison between maps and years. These maps were generated in Processing using a combination of existing libraries and custom modules.



(a) Visualization on SOS showing radial bar graph, legend, and annotation

(b) Radial bar chart for Winter Olympics 2014 showing participants and medals won per country

Figure 10: Spherical visualization of the Winter Olympics

Figure 11 shows a combination of the techniques created for the Winter Olympic dataset as an infographic with particular care taken to show medal counts with an underlay of the 2014 medal serving as the base of a semi-transparent pie chart depicting gold, silver, and bronze medals won. This circle is surrounded by a gray circle sized to correspond with participation. This information is reinforced by the bar charts at the bottom of the graphic where national flags serve as the anchor for a stacked bar chart of medals won. By reinforcing what the viewer is seeing this flattened image drives home global participation in several ways. It may also easily be wrapped for display on the SOS.

5.2 Conglomerate Distortions

While much work on the sphere is geo-referent, fine artists Sala Wong (Associate Professor, Indiana State University) and Peter Williams (Indiana University Visiting Faculty) have created art that takes advantage of the natural affordances and distortions of the medium. *Conglomerate Distortions* is a series of immersive animations that reflect upon technology's impact on our immediate surroundings, and emerge from Wong and Williams's practice of hypertourism, or visiting a range of tourist spectacles within a highly compressed timeframe (Figure 12). From their travels, the artists created the multichannel video installation with panoptic photography and animation. The installation has been shown in Microworld, a group exhibition at The Space in Hong Kong. Future exhibition plans include the 2015 Lumen Prize Exhibition and a fall 2014 show at Indiana University, using the SOS.

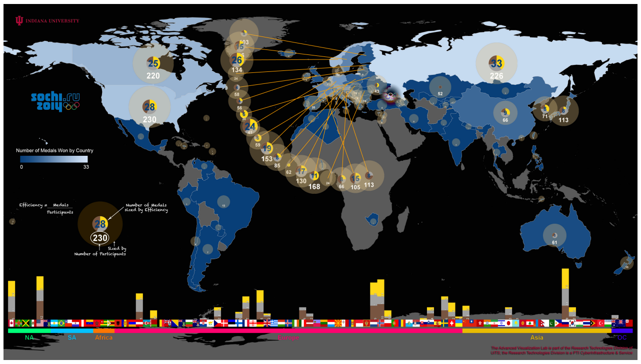


Figure 11: Infographic: Winter Olympics 2014 created by the AVL at Indiana University.

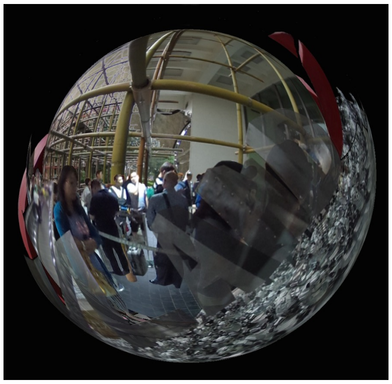


Figure 12: Piece from *Conglomerate Distortions* by Peter Williams and Sala Wong

Wong and Williams build upon the work of other panoptic and VR photographers such as Luc Courchesne, Dan Bailey, Marnix de Nijs, and Denis Gadbois. Courchesne, for one, tells the story of his movement from 2000-2005 via a cadrioptric lens, interrogating concepts of place, subject, and the construction of the world we see. In his blog post, "Missing Mercator: Alternative Projections," Bailey, a professor of Visual Arts and Director of the Imaging Research Center at UMBC, Baltimore, Marlyand, defamiliarizes Mercator projections, which are useful for navigation, and works with hyperbolic projections as ways to represent space artistically [2]. We plan to continue this partnership and further explore the variety of purely artistic possibilities the medium of a sphere offers.

5.3 Spatial Humanities

Figure 13 shows the distribution of the *Harry Potter and the Philosopher's Stone* in its corresponding translation around the world. This work was part of a digital humanities course at Indiana University in which students had the opportunity to learn about mapping and spherical visualization as part of their class. This visualization went through several stages as the student pared down the number of translations available (67 official versions) to languages that would map to the world. Mapmaker Vic Fieger kindly gave his permission to use the base map, originally showing language distributions worldwide, filtered down to the nine languages covering the most land area. The project team then decided where to place translation titles based on space available on the globe and sensitivity to colonial language dispersion. Finally, a free font was downloaded to give the visualization a much more Harry Potter-esque feel.

Figure 13: Visualization of translations of Harry Potter and the Philosopher's Stone

5.4 Engaging Digital Signage

Many large-scale displays have been used to engage the public with digital signage. For several events at Indiana University, the SOS was employed to disseminate information about gatherings going on in the same space as the sphere (Figure 14). Indiana University scientists have developed tools to aid in NASA's Operation Icebridge, which monitors polar ice sheets. Participants gathered to share their experiences with the general public beneath Figure 14a. Similarly, an engaging graphic combining text and art from the Kinsey Institute's collection was wrapped around the equator of the sphere over a greyscale rendering of the earth for an evening talk about the Institute (Figure 14b). Both uses surprised and engaged the audiences.

(a) Operation Icebridge Lecture (b) Kinsey Institute Open House

Figure 14: Digital Signage Examples

5.5 History of the Soccer Ball

In conjunction with the 2014 World Cup, IU students and staff created geospatial information maps similar to those generated for the Winter Olympics. The team also created textures for each of the World Cup soccer balls used since the Cup began in 1930. The spherical SOS display provided a natural representation that exactly fit the physical artifacts, and it aptly demonstrated the historical evolution of ball technology in an intuitive manner for lay audiences (Figure 15). In addition, a touch table application was developed so that viewers could choose a ball to project onto the sphere while learning more about its design and history.

6 CONCLUSION

Traditional globes are established, well-understood, and universally-liked technology. Relatively speaking, digital spherical displays are a still in their infancy, yet have already shown themselves to be a highly compelling, versatile, and effective technology, especially for presentation of scientific and information visualizations and creative works in public spaces. The number of digital sphere installations is on the rise, and while still far from ubiquitous, they will find their way into more and more public, semi-public, and private spaces. A thorough understanding of the unique affordances and challenges of these displaysalong with a documented set of proven techniques to address these challengesshould help these deployments to be even more successful.

(a) 1934 World Cup Ball (b) 2002 World Cup Ball

Figure 15: Natural Object Projection Onto the SOS

In this paper, we presented our collective experiences and knowledge with regards to spherical displays, and described the most salient features and benefits of spherical displays and the underlying technologies and installation considerations. Important design considerations, layout and warping methods, effective visual and aesthetic encodings, and techniques for facilitating storytelling and inviting user interaction were also described. Finally, the design considerations were presented with a variety of examples across many domains using a diversity of software tools.

Spherical displays offer unique characteristics that can enhance perception and provide a natural environment for visualization. They can provide a far-reaching outlet for data, information, and art dissemination and presentation.

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