

Direct Rotational Interaction With a Spherical Projection

Stefanie Kettner, Christopher Madden, Remo Ziegler

This paper investigates a design for a new form of interactivity with information projected onto a spherical surface. This form of interaction is related to the direct rotation of the spherical surface itself. Traditional methods of computer interaction use a representative format, such as the movement of a mouse representing the motion of a cursor on a flat screen. This representative interaction often becomes less obvious with a three dimensional object, as there is often an exact view position required. The rotational interaction method developed provides a more direct physical connection with the data interaction upon a sphere by mimicking globe style rotational interaction. The authors discuss in detail the design and implementation of the rotation interactivity, including a discussion of the limitations involved.

Displaying and interacting with information and other forms of data is a challenging task that aims to make the most of the information and resources available in this era of increasing technology. Much research has been conducted into the area of humans interacting with computers. This has generated a number of interactive devices from light pens and keyboards, to the mouse, and more recent advances in touch sensing and camera based visual interaction (Jacobs 1996), (Myers 1998). This research has helped to develop tools that we can use to interact with, and understand data. With the modern

development of projection technologies, a wide variety of new possibilities are also available for use in displaying information.

The advances of computing power, projection capabilities and interactive tools have affected the possibilities of displaying information dramatically. The increase in computer power has allowed for more complex representations of the data through a variety of factors. These factors include better colour representations, faster construction of layouts, smoother animations, real-time image warping, and the ability to project images upon planar and non-planar surfaces (Raskar 2001), (Raskar 2002), (Raskar 2003), (Dietz 2004). Image warping allows for information to be transformed from a two dimensional image to be displayed on a computer screen into an image shaped to fit on to other surfaces, including a spherical surface. Information visualisation can use these techniques to turn abstract and often complex data from a high dimensional data set into information that is more easily understood. Research in this area uses many techniques including shapes, structures and layouts in order to display data in a more informative manner (Kaufmann 2001), (Battista 1999).

Interactions with the data and images presented using information visualisation can help to engage people's attention and lead to more understandable visualisations. It allows people to manipulate the information as they desire, and learn from those manipulations as well as other formats for the information, as well as providing a method to view large information sets.

This paper provides a design for a spherical projection display that allows for a direct physical interaction, as well as using more traditional mouse style inputs. The usefulness of the spherical display relates directly to the types of information that can be presented, and how people can interact with that information. Though this paper does not aim to fully investigate the potential uses, it does provide a discussion of

the motivation of the project. This motivation comes largely from the Information Visualisation and Cartography fields for displaying accurate spherical pictures or video data. Research in the Information Visualisation field indicates that the spherical surface may provide some benefits to data representation, especially in the area of graph drawing (Ritter 1999), due to a number of factors, including its constant curvature and absence of boundaries. This shows there is no accurate mapping of spherical data onto a flat surface. This phenomenon can be important in areas such as Cartography, as well as more general spherical data and image visualisations (Wu 2005). The physical interaction proposed also aims to create a more direct interaction with the sphere, ensuring that the projected image moves as the user perceives that it should. This does not always occur with representative interaction, as explained in Section 3. The art world has also recognised the visual attractiveness of projecting onto an object in displays such as OmniGlobe, exhibited by ARC Science Simulations. The authors are aware of only a few other spherical displays, such as OmniGlobe. These differ significantly from our proposed design by being fixed screens, with no physical interaction except walking around the sphere.

The following section specifies the goals of this project. Section 2 describes its construction as well as implementation of the projection and the applied interaction. The results of a small survey of computer-literate users are presented in section 3, where they have compared the different interaction types. Section 4 discusses some possible uses of the spherical display, including those already specified in the introduction. Finally, concluding statements are presented in section 5.

1. Goals

The primary goal of this project is the creation of a research platform named ViBall that can be used to further investigate spherical projections, and interaction methods that can be used with those projections. The investigations to be performed with this platform will

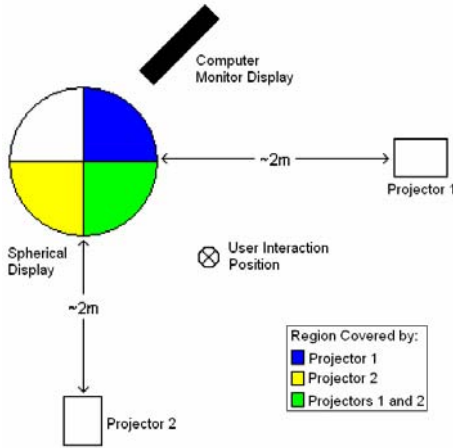
look into the spherical representation of data, and the benefits that can be obtained using these methods, as well as the interaction methods that can be used to view and analyse the information provided.

This paper will focus upon the design and development of the physical interaction platform, as well as a small survey conducted into the usability of the rotational interface. Though this survey is not large enough to provide statistical results, it gives an indication for further research into new possibilities and limitations of spherical display devices and the interaction methods used. In a final discussion we will describe possible uses of the platform, which will require further investigation in the future.

2. Spherical Display Design

This section discusses the design and implementation of an interactive spherical display. This paper includes a discussion of the concepts involved in the creation of the display to give a more comprehensive understanding of the design. For the purpose of this paper the interactive styles are separated into two categories. Physical interactions are considered to be those interactions that involve touch and movement of the display itself, whilst representative interactions involve the movement of another device to represent the motion of the image that is required, such as rotating a trackball or moving a mouse.

The spherical display design proposed in this paper, named ViBall, consists of a spherical display surface mounted on a stand. Two projectors aim to cover a large portion of the visible section of the sphere, with a region of overlap on the surface where the projectors meet, as shown in Figure 1 below. These projectors display images of the computerised spherical model of the information onto the spherical surface itself. Optical mice are positioned both underneath, and behind the sphere to measure its physical rotation, which in turn updates the projection. A standard computer monitor is also included for displaying



further information, such as a hierarchy structure of the information or image, which may be difficult to produce on the spherical surface itself.

Figure 1: ViBall spherical display setup giving approximate positioning

2.1. Spherical Surface Design

The sphere was chosen so that it was small enough to be both completely within a persons view, and rotated easily. The sphere also needed to be large enough to display a reasonable amount of information on the surface. With cost and time considerations in mind, a ready made sphere was purchased in the form of a gym ball. This hollow plastic ball has a radius of approximately 36.5 centimetres, and a minimal amount of surface detail. To increase the picture quality the ball was painted white, and a matte spray was applied. This created a low cost sphere with a functional projection surface that also allowed for some surface detail to be used in calculating the relative positioning of the sphere and the projectors for accurate calibration (Raskar 2002). If the sphere is accurately spherical and smooth, then it will provide a good projection surface. If the sphere is too smooth, then it can become difficult to detect the rotation using the simple optical mouse, and more specialised equipment will be required to detect the rotation. Sensors embedded within the sphere to detect the rotation would provide the best possible projection surface, though this is a higher cost alternative.

2.2. Projection Location and Calibration

This project uses two centre throw projectors to project onto the outside surface of the sphere. These projectors are mounted approximately 90 degrees apart so that their projected images will cover the surface of the sphere as shown in Figure 1. This positioning covers the area viewed by a person interacting with the device from the front, though is not ideal for covering the entire sphere. More projectors could be used to cover the entire surface of the sphere if it was to be placed in the centre of a viewing area. The positioning of the projectors as shown in Figure 1 also creates a region where the images overlap. This region of overlap is the area where people are most likely to interact with the device. By creating this overlap, shadows cast by hands entering the projection region are minimised because the second projector covers the shadow cast from the first projector. Areas of shadow from both projectors usually fall in a small area beneath the hand, which is often occluded by the hand itself.

This overlap region requires accurate calibration of the projectors to ensure that the projected images properly overlap each other. The calibration uses a model of the physical setup inside a Java3D virtual universe. A spherical model is used for the physical sphere, with virtual cameras modelling the physical projector locations, which provide the view of the model. This positioning of the virtual cameras is determined as projector matrices through the calibration process. The software for calculating these matrices was provided courtesy of the Mitsubishi Electric Research Labs (Raskar 2002) and was slightly adapted for our research purposes. This software calculates the internal and external parameters of the projectors and their virtual cameras by taking a set of points with known 3D coordinates on the sphere's surface, and finding the corresponding projector pixels that illuminate them. These matrices contain the intrinsic and extrinsic values for each projector (Raskar 2002). Together, these matrices represent the offset of the projectors

from each other relative to the sphere they are projecting upon. The view platform for the computer monitor uses the default camera settings in Java3D, which provides a view centred along the model's z-axis, as shown in Figure 3. This is important, as the representative rotation is based upon this view of the model.

2.3. Spherical Model Creation

The computerised spherical model is generated as a Java3D virtual universe. It is necessary to build three identical virtual spheres in the universe in order to accurately set different values important for the image blending process. Each projector, and the computer monitor, looks at their copy of the sphere from different positions, generating the three relative views of the model as shown in Figure 2 below. The initial test environment uses a texture mapping application in order to determine the correlation between the view port settings of both projectors. A world map developed for spherical surfaces was obtained courtesy of NASA/JPL-Caltech, and was image warped as a texture map around the sphere. This provided a model to see correlation of the images from each projector in the overlap region to test if they matched. A close match is required to eliminate ghosting of the image on the sphere, where a feature is projected at a slightly different location by each projector, making the image look blurred. This style is ideal for viewing spherical images, and can be easily adapted to display image sequences and videos.

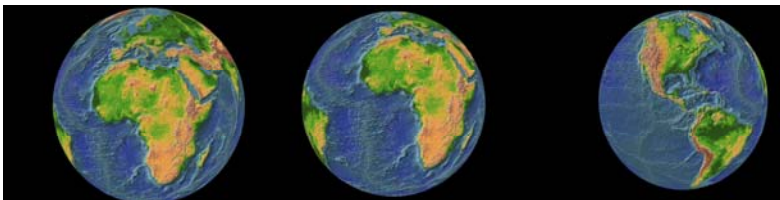


Figure 2: Displayed images from left to right, projector 1 (left projector), the computer screen, and Projector 2 (right projector)

The application developed also accepts inputs to generate the spherical model using StripArrays, or texture images. This data can be loaded and used to construct the 3D model to be viewed. This model can represent a variety of data types with information encoded into points located on the virtual sphere. This allows for a variety of parameters, including colour or position, to represent different information as it is obtained from a data set. The method mentioned previously, (Raskar 2002), is used to warp this spherical information onto the physical sphere for display. The possible uses for the sphere to display information are described further in Section 4 below.

2.4. Interaction Design

This design incorporates both the physical and representative styles of interaction with the spherical display. The representative interaction is the software interpretation of the representative style movement whilst the left button is pressed, and includes the mouse, trackball, and gyration mouse devices. This method of interacting with the mouse motion is a common practice in the computing environment. This representative interaction is effective after a short time familiarising yourself with the method used. The advantage of this method is that it is fully supported by Java3D and familiar to users. A variety of devices that produce mouse style motion can also be used, such as trackballs, mice, or gyration mice. This interaction is limited by its representative nature.

The direct rotational interaction has a physical link between the interaction and the data presented. This interaction is designed to be a physical addition to the existing mouse and keyboard-based interactive structure of the computing environment. The interaction is based upon the readings obtained from two optical mice. These mice are positioned such that they can detect the rotation of the sphere around the x, y, and z axis. They are positioned with one mouse underneath the bottom centre of the sphere to detect the rotation around the z axis in the x-y

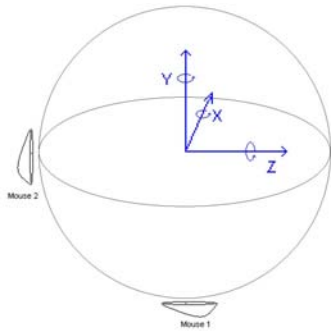


Figure 3: Optical mouse placement for detecting the spherical rotation

plane, and the second mouse is at the centre rear of the sphere and detects rotation around the x axis in the y-z plane as well as rotation around the y axis in the x-z plane. This positioning of the mice makes the separation of the rotation into the different axis simple, as shown in Figure 3.

Once the rotation is detected, it is used to rotate the virtual model of the sphere based upon a scaling factor. This scaling factor represents the difference between the actual motion of the sphere, and the units that the mouse detects the rotation with. By using the correct scaling, the projected sphere will move at the same rate of rotation as the physical sphere it is projected upon. This physical connection with the sphere ensures that the projected image will move in conjunction with the direction that you perceive you are rotating it.



Figure 4: Spherical Display Configuration showing the ViBall and projectors

3. User Survey Results

The user survey was a small experiment, due to the short nature of the development phase. The aim of the experiment was to get a degree of broad information about the interaction styles, rather than to fully assess the interaction obtained. This provides feedback on the device that can be used to give better direction to further research, and developing a better prototype based upon more accurate requirements. The results are included because of their indication about the nature of the physical interaction when compared to other more representative styles of interaction. Further experiments and investigations are needed to truly assess the full impact of this form of interaction.

Information was collected for the experiment about using four different interaction tools to perform the rotation of the sphere. These tools are the physical rotation of the sphere, a mouse, a trackball, and a gyration mouse. The gyration mouse is similar to a conventional mouse, except that it moves the cursor based upon the motion of the mouse through the air, as well as working like a normal mouse along a flat surface (<http://www.gyration.com/ultra.htm>). As a handheld cordless device, this allows the user to move freely, whilst still interacting with the device. These devices are separated into the two broad categories of physical and representative interactions, as described at the start of Section 2. The information about the interactive device usage obtained is aimed at a qualitative comparison of the devices, based upon how easy and intuitive they were to use.

The experimental setup is shown in Figure 4 above. It consists of running the spherical display's demonstration application, which projects the world map of the Earth. Seven computer-literate users, mostly with a research background, were then told the devices that could be used to interact with the sphere. They then needed to determine how they worked in order to perform simple tasks. These included positioning a country, such as Australia, at particular locations and orientations, or

moving portions of the map into view. The users were then asked to rank the devices according to how easy they were to use, and comment upon the interactive devices and the limitations that they perceived. The results are included in the following table as average results from the seven users studied. The interaction ranking is the averaging of the user rankings of the interaction tools. The rankings range from 1, being the highest ranking, to 4, the lowest ranking. The 'Limitations Identified' column provides the percentage of users, out of the seven participants, who noticed the obvious limitations associated with the interaction device. The user comments are also provided below to highlight some of the problems associated with the interaction techniques.

Table 1: User Survey Data Averages

Interaction Tool	Interaction Ranking	Limitations Identified (as percentage)
Gyration Mouse	1	86%
Physical Rotation	2	43%
Mouse	3	71%
Trackball	4	71%

This small user survey experiment identified many limitation factors to the interactive styles used. The factors identified by the users are:

- The limitation of visibility when actually performing the physical rotation of the sphere.
- The limited stability of the ball when it is rotated too fast, or in a rough manner.
- The relative perspective problem associated with the representative interaction style.

3.1. Physical Limitations

The physical interactive style provides a direct link between the physical sphere, and the information presented upon it. The main limitation of this style relates to the ability to see the full view of the sphere. When

you are close enough to touch and rotate the sphere, you are occasionally blocking the projectors. The impact of this limitation is minimised by interacting within the overlap region between projectors. The problem of your hands blocking your view of other parts of the sphere cannot be minimised, however. This fundamental problem may require users to stand back from the sphere to investigate the overall image. It is interesting to note that only two of the seven users made a comment upon this, indicating that they would prefer to stand back and view the complete data and interact from this position.

The second problem associated with the physical rotation involves the construction of the sphere. When users rotate the sphere in a rough or fast manner, the ball tends to bounce a little on its stand due to its light nature. This bouncing disrupts the readings of the sphere rotation, and can cause a “sliding” effect of the image on the sphere – sliding in the sense that the projected sphere is not rotated according to the physical ball rotation. This artefact was observed by two users who adapted their behaviour to rotate in a slower, gentler manner. This could also be minimised by using a heavier, sturdier sphere and stand structure, or by implementing a better method of guiding the rotation, rather than simply mounting the sphere upon rollers.

3.2. Representative Interaction

The representative interaction technique can enable users to stand back from the sphere and see the full image. It does, however, create the relative perspective problem, which arises from the fact that the actual and representative models have relative orientations to each other. The representative interaction performs the same physical rotation regardless of the users’ relative orientation to the physical model. This orientation is important because the users’ perception of the rotation direction is likely to be different to the rotation that occurs unless, they are oriented correctly relative to the physical sphere. This occurs regardless of the fixed or portable nature of the interactive device. With

fixed devices, such as a mouse with a small desktop area, it is possible to fix the device in the correct relative location.

The relative perspective problem is not as important when using a flat screen projection, as the view of the model is always oriented in the same direction relative to the interactive device. The computer screen included in our design can be used for this purpose, though it is intended for displaying extra information rather than being an interactive viewpoint. Five out of seven users noted this limitation when trying to use the sphere with the trackball and mice. Some users used these tools only whilst viewing the computer monitor, which provides the correct representative orientation with the input device, ensuring it worked properly. With the gyration mouse all users tended to walk partway around the sphere and most noticed that the rotation of the device was not necessarily what they expected from their current view. This indicates that care needs to be taken with portable devices such as the gyration mouse to account for this difference in the expected and actual rotations of the projection. Additional position tracking could be used to overcome this limitation by adjusting the rotation to occur based upon the users' view of the sphere. This would require extra hardware and complicate the rotational software functions.

3.3. Interaction Comparison

The ranking of the devices in Table 1 also provides some interesting information. The gyration mouse was ranked as the best input because of its portability and the ease with which you can view the entire display, though there was an indication that it takes a short period of less than a minute to become familiar with the device. The physical interaction was regarded to be fairly intuitive, though users indicated the bouncing nature of the sphere could make the interaction hard to use. Users also tended to want to stand back from the sphere to some degree to view the whole image. The mouse was ranked third by the users because most people were familiar with it, with the trackball being

ranked last. Interestingly, only one user picked up the trackball from the desk and held it in their hand to rotate it, providing some degree of movement from the table. This user thought the trackball provided a much better interaction with the sphere than the mouse as it mimicked the rotation of the sphere, if only in two dimensions.

These factors and results provide an interesting insight into the limitations of both styles of interaction with three-dimensional devices, and especially our spherical display. They indicate that a very stable physical interaction can be useful, but the ability to stand back and view the entire display is also important.

4. Possible Uses

Information visualisation relies heavily on visualisation tools to assist the user in representing large and complex data sets. High dimensional data can now be visualised using techniques such as self-organising maps (Kohonen 1997). The non-Euclidean self-organizing map (Ritter 1999) can help to visualise directional data on 3D surfaces such as a sphere, especially where the natural data model is spherical. This occurs in many data sets, such as the CAIDA internet traffic data set (http://www.caida.org/analysis/topology/as_core_network/), shown in Figure 6. Ritter also suggests the closed nature of the spherical surface can be beneficial to the problems associated with the boundaries of self-organising maps that occur using a two dimensional representation of some data forms. Combinations of high dimensional data and nonlinear mappings of the data and rotations may also be able to provide other opportunities for information displays and interactions in the future.

Research has shown there are no accurate one-to-one mappings of a spherical surface onto the plane (Ritter 1999). Such a mapping creates errors around the boundaries of the plane, and also a distortion of distances when the curvature is removed to create the planar representation. The globe is a good example of this phenomenon as it is

inherently spherical in nature. The spherical display properties are currently being investigated using this display (Wu 2005).

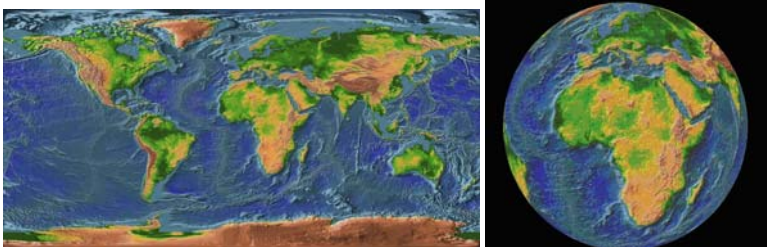


Figure 5: 2D world map before and after warping to a sphere

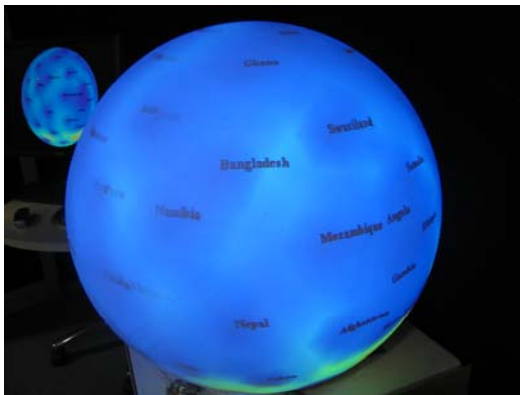


Figure 6: 3D Visualisation showing the similarity of countries in 1990 based upon factors such as birth and death rates based upon physical location (Wu 2005).

Interaction is also an important feature for visualisation tools, as it assists the user in exploring and analysing the displayed data. Rotational interaction is often available with three dimensional data, though many currently used interactive devices only work in two dimensions. This is being rectified with the development of 3D mice and other devices, though these often take a representative interaction style that has some limitations with a physical display, as mentioned earlier. The physical interaction creating a rotation that matches the actual

rotation of the projection surface would seem to be more intuitive, though further user testing is required to prove such a hypothesis.

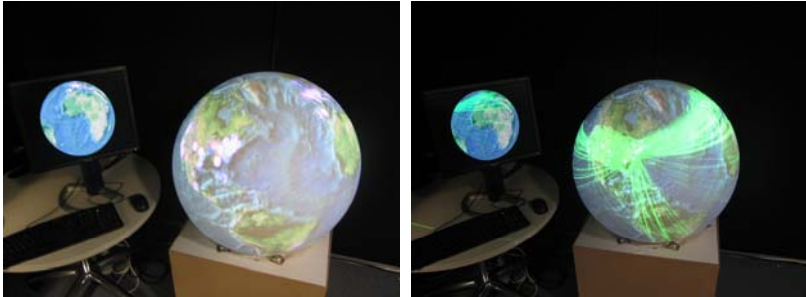


Figure 7: Left shows the world overlaid with nodes showing high internet usage. Right shows the flow of internet data between nodes. The data used in this research was collected as part of CAIDA's skitter initiative, <http://www.caida.org>. Support for skitter is provided by DARPA, NSF, and CAIDA membership.

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5. Conclusion

This paper has presented a new design for a spherical display with a physical rotational interaction, as well as the possibility for more traditional representative interaction. The design presented is simple and effective, and minimises the costs involved by using simple existing technologies in its development. The user survey has shown that the concept of using physical rotation has both benefits and limitations over

representative style interactions. The combination of both physical and representative interaction into a single research platform will allow for a fuller investigation of impact upon the style of user interaction. The spherical display itself will also allow for further investigation into spherical data forms and applications, without requiring interactive virtual displays. These can range from displaying images or image sequences such as videos on a spherical surface, to more complex multidimensional data that is encoded into positional or colour-based spherical graph layouts, to data nonlinearly mapped upon the spherical surface to highlight key information. This could be useful to many research areas from cartography, to the Information Visualisation field.

Acknowledgements

We would like to acknowledge some people and organisations that have allowed us to conduct this research without being directly involved. Firstly we would like to thank Mitsubishi Electric Research Labs (MERL) who have allowed us to adapt their calibration code for use on a spherical model. We would also like to thank NASA/JPL-Caltech (<http://maps.jpl.nasa.gov/>) who have allowed the use of their images produced for creating true spherical world maps. We would like to acknowledge that National ICT Australia is generously funded through the Australian Government's *Backing Australia's Ability* initiative, in part through the Australian Research Council. Finally we would like to acknowledge Yin Wu, Ben Yip, and Shea Goyette for their work in generating data sets to display on the sphere, as well as the CAIDA skittner initiative (www.caida.org) for their internet traffic data.

References

- G. Battista, P. Eades, R. Tamassia, I. Tollis (1999) *Graph Drawing, Algorithms for the visualization of Graphs*, Prentice Hall.
- G. Calafiore (2002) *Approximation of n-Dimensional Data Using Spherical and Ellipsoidal Primitives*, IEEE Trans. SMC, 32(2): 269-278.

- P. Dietz, R. Raskar, S. Booth, J. Van Baar, K. Wittenburg, B. Knep (2004) *Multi-Projectors and Implicit Interaction in Persuasive Public Displays*, Advanced Visual Interfaces (AVI), ISBN: 1-58113-867-9, p209-217.
- R. Jacob (1996) *Human-Computer Interaction: Input Devices*, ACM Computing Surveys (CSUR), 28(1): 177-179.
- M. Kaufmann, D. Wagner (Eds) (2001) *Drawing Graphs, Methods and Models*, Springer-Verlag Berlin Heidelberg.
- T. Kohonen (1997) *Self-organizing maps*, Springer Series in Information Sciences. Springer, second edition.
- B. Myers (1998) *A Brief History of Human-Computer Interaction Technology*, ACM interactions. 5(2): p44-54.
- R. Raskar, G. Welch, K. Low, D. Bandyopadhyay (2001) *Shader Lamps: Animating Real Objects with Image-Based Illumination*, In Proceedings of the 12th Eurographics Workshop on Rendering, p89-102.
- R. Raskar, R. Ziegler, T. Willwacher (2002) *Cartoon Dioramas in Motion*, 1st Symp On Nonphotorealistic Animation and Rendering (NPAR).
- R. Raskar, J. Van Baar, P. Beardsley, T. Willwacher, S. Rao, C. Forlines (2003) *iLamps: Geometrically Aware and Self-Configuring Projectors*, In Proceedings of SIGGRAPH 2003, ACM Transactions on Graphics (TOG), ISSN: 0730-0301, Vol 22, Issue 3 p809-818.
- R. Raskar, J. Van Baar, P. Beardsley, C. Forlines, P. Dietz, Alan Esenther, D. Leigh, K. Ryall, C. Shwn, S. Shipman, B. Yerazunis (2003) *Intelligent Clusters and Collaborative Projector-based Displays*, NSF Lake Tahoe Workshop on Collaborative Virtual Reality and Visualisation.
- H. Ritter (1999) *Self-Organizing Maps on non-euclidean Spaces*, Kohonen Maps, pp 97-108. Amer Elsevier.
- A. Sangole, G. Knopf (2003) *Visualization of randomly ordered numeric data sets using spherical self-organizing feature maps*, Computers & Graphics, 27: p963-976
- Y. Wu, M. Takatsuka (2005) *The Geodesic Self-organizing Map*, accepted into Visualization and Data Analysis, San Jose, California.