

# Immersive Data Visualization with Virtual Reality

Aditya Sankar

University of Washington, CSE

adityas@uw

## ABSTRACT

There has been a resurgence of interest in Virtual Reality (VR) with the advent of several consumer-ready head mounted displays. And while VR has a long standing tradition in graphics literature traceable to the early 90's, little research has been conducted on the implications of modern VR and 3D displays on Data Visualization. In this work we explore how to create immersive 3D data visualizations and subsequently interact with them effectively using novel modalities such as head pose. We hypothesize that an immersive data visualization experience provides benefits beyond traditional desktop counterparts and that a user is better connected to the data, both perceptually and emotionally.

## Author Keywords

Data Visualization; Virtual Reality; Human Factors; Project Report;

## ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

## INTRODUCTION

Traditional data visualizations are typically two dimensional. They are relatively easy to render, more familiar and well studied. However, they are limited by screen real estate and must resort to interactions such as panning and zooming to present datasets that do not fit into the bounds of the screen. Also, it is challenging to represent more than two dimensions of the data on such displays. Attempts have been made to represent data in three dimensions, but they have largely been seen as unsuccessful in the literature. We argue that this is because the 2D display mechanisms used were insufficient to present 3D data. On a conventional display, 3D visualizations are projected down to two dimensions for consumption, but these tend to provide little cognitive benefit, since the viewer only observes foreshortening and occlusion effects, but does not experience the critical depth cues provided by parallax. We posit that presenting 3D data with stereoscopic displays can enhance the salient characteristics of the data presented and reveal insights faster and more convincingly.

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Researchers have used virtual reality displays such as caves [3], hyperwalls etc. in order to alleviate some of the limitations of 2D displays. However, cost is a prohibiting factor in these systems, ranging from several thousand to multiple millions of dollars in set up.

Recently, inexpensive commercially developed VR hardware such as Oculus Rift, Samsung Gear VR, Valve SteamVR have opened up a possibility of creating powerful and portable 3D experiences on affordable desktop, laptop or mobile hardware. Virtual reality displays have the following benefits over 2D displays:

- Images are presented in stereoscopic 3D: This provides a strong sense of parallax and absolute scale (that far surpasses 2D renderings of 3D scenes on flat displays)
- The viewer's gaze/head movements are tracked in 6-dof, enhancing the illusion of virtual reality and also providing a novel interaction mechanism.
- Much more portable and cost effective, compared to cave installations.

In this work, we use Oculus Rift [11] (Figure 1) to visualize two egocentric 3D spatial-temporal datasets; asteroids in our solar system and a simulation of a biological neural network. The goal is to enable the viewer to get a better sense for the 3D data and interact with the data directly via gaze and head movement. We also explore more intentional interaction with data such as brushing and linking using head tracking and a clicking device.



Figure 1. Oculus Rift DK2.

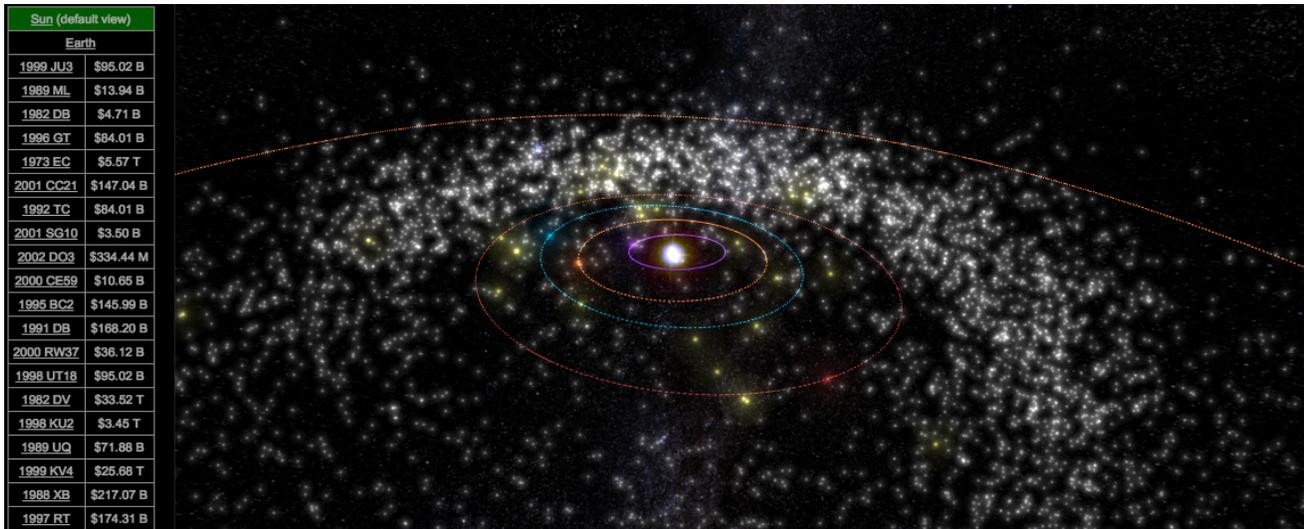


Figure 2. The original web visualization of Asterank data, projected down and displayed in 2D.

## RELATED WORK

VR has demonstrable benefits in analysis of spatial and volumetric data. Early work has investigated the advantages of VR displays in the fields of entomology [8], brain MRI [15], shape understanding [4] and 3D path understanding [13]. While these studies unanimously describe VR as having a positive impact on perception, they all rely on CAVE-like displays that are expensive and not widely available. Possibly because most of the work was conducted prior to the popularity of low cost VR display technology.

Donalek et. al. [5] conduct some closely related preliminary work on benefits of VR using commercially available head mounted displays. Their focus is on high-dimensional “big data” and their work primarily explores various ways in which 8-dimensional data can be projected down and displayed in 3 dimensions using VR. We extend this line of work and explore how users can interact with such datasets.

We explore two egocentric spatial-temporal datasets, since they are easily interpreted by users owing to our the natural 3D visual stimuli of our own environment. Asterank [1] (Figure 2) is one such accessible data source that catalogs 600,000 asteroids based on name, mass, orbital parameters, estimated mining value etc. Currently the Asterank 3D interface allows the user to pan and zoom, but they cannot directly interact with the data in an egocentric manner.

We also visualize a simulation of a 3D brain neural network [10] with immersive virtual reality. While this visualization is not grounded in actual biological data, it indicates the value of virtual reality in the visualization of large multi-dimensional networks.

To interact more effectively with this data, we will build upon well studied principles of 3D interaction [2] for view manipulation and selection. We use egocentric ray casting [12] [6] controlled by gaze and a clicking event in order to interact with data.

## OVERVIEW OF METHODS

For practical purposes, the project was split up into two parts each exploring a particular aspect of VR visualization. The first is exploring 3D interaction and manipulation of data points. This part was implemented in Unity3D from scratch. The second part of the project involved porting existing WebGL visualizations into Virtual Reality and exploring potential benefits of stereoscopic displays. All the development and testing was performed on a HP Spectre x360 laptop, with a Intel HD5500 integrated graphics card running Windows 8.1. Both parts of the project rely on a pre-release software development kit provided by Oculus that communicates with the head mounted device and returns the position and orientation of the viewers head. The head mounted device contains a 1920x1080 pixel display which can be attached to the computer as an extended monitor.

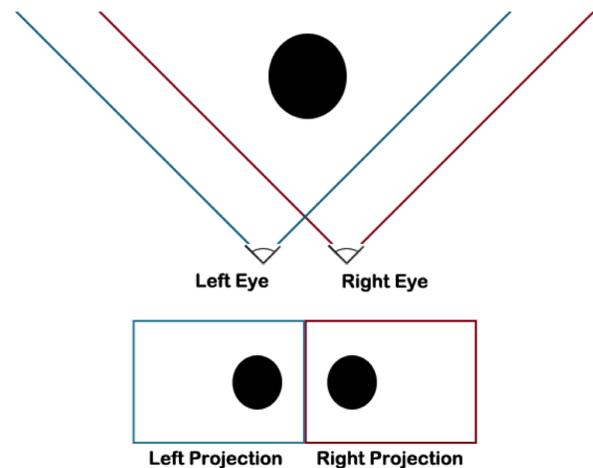


Figure 3. Rendering images in stereoscopic 3D with a camera each for the left and right eyes.

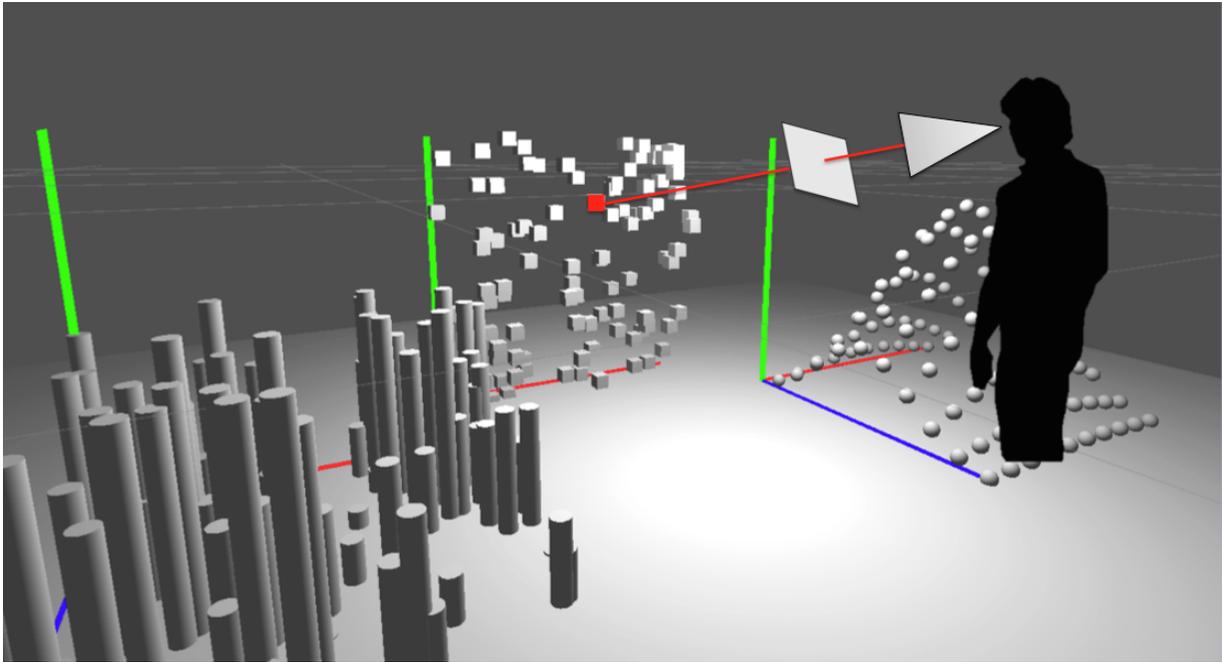


Figure 4. A screenshot of the Unity environment with the user (shown as a silhouette), performing a brushing operation via ray casting.

In order to present graphics in stereoscopic 3D, the system needs to render the virtual scene from two cameras, one for each eye, as shown in Figure 3. The virtual cameras are separated by an inter-pupillary distance (IPD) which is equal to the physical distance between the eyes of the observer. Once the view from each camera is rendered, a barrel distortion must be applied in order to counteract the dual pincushion distortion of the lenses in the display (Figure 5). Understanding these rendering techniques [7] in detail was imperative to creating VR content and a valuable learning aspect of this project.

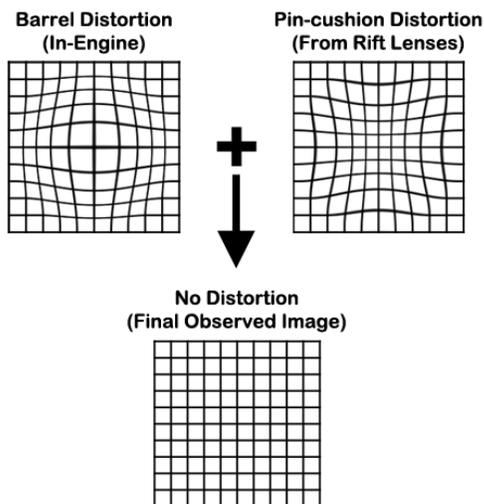


Figure 5. Counteracting the lens pincushion distortion by applying a virtual barrel distortion.

There is also a manually specified scaling factor that relates the size of the real world (in meters) to that of the virtual world (in arbitrary units). The scaling factor was set as 1.0 for the Unity demo and determined empirically for WebGL visualizations since their virtual coordinate system is not based on reality.

We describe the two parts of the project in greater detail in the following sections:

### INTERACTION: BRUSHING AND LINKING

In order to explore human-computer interactions in the context of VR data visualization, we created an virtual environment (Figure 4) containing abstract data that allows users to perform interactive visual analysis via brushing and linking.

The environment consists of a plane upon which the user is standing, surrounded by three 3D scatter plots. In each scatter plot, data points are represented as primitive shapes (cubes, cylinders and spheres) and each plot represents a particular projection of the original dataset. In other words, the user is presented three plots of a high dimensional abstract dataset that has been projected into three arbitrary data dimensions, each of which are mapped to x, y and z of the virtual environment. For the purposes of this experiment, we used dummy data that was randomly generated.

To perform brushing, the user indicates intent by using a clicking device in their hand (similar to a mouse or presentation clicker). Clicking and holding the button enables 'brushing mode', wherein the user simply looks towards the data points of interest to perform a selection. When the center of the users view coincides with a data point, it is selected, as indicated by a bright red color applied to the data point. A

virtual crosshair is provided to assist the user with precise selection tasks.

To perform the selection action, we use 3D ray casting. A ray is projected along the principal axis of a third virtual camera that is centered between the left and right eye cameras. This ray is cast into the scene and efficiently intersected with 3D objects in the scene using geometric collision detection techniques. The colliding object is returned as a result of the ray cast operation and the material color of the object is set to red, to indicate selection. Linking is performed by updating the selection in the corresponding data points in the other scatter plots. Since the underlying data table is the same for all three plots a simple 'isSelected' flag is assigned to the data point when it is selected. Querying for this flag during the rendering of the other plots enables the linking operation.

### WEBGL VISUALIZATIONS IN VR

Several 3D visualizations already exist on the web. The second part of this project aimed to port these visualizations to virtual reality in order to understand potential benefits provided by VR. It was decided not to re-implement these visualizations from scratch, as it would result in redundant effort. Especially for the asteroid dataset that requires complex physical simulations.

With the help of an open-source library [14], it was possible to communicate between a WebGL application and the Oculus Rift Hardware. A certain amount of tweaking was required in order to update vr.js to run with the latest Oculus SDK. The biggest challenge was to orient the coordinate systems of the head mounted device and the WebGL applications, which were not designed to be used with virtual reality. The quaternions returned by the head mounted device were converted to Euler angles and rotated in a particular order (X before Y before Z) to align them to the WebGL coordinate system.

Once the virtual cameras were setup and linked to the data provided by the head mounted display, the distortion was applied using shaders and the resulting stereoscopic rendering was pushed to the device. The contents of the visualizations are discussed below:

- **Asterank [1]:** Asterank is a scientific and economic database of over 600,000 asteroids. The author has indexed data such as asteroid mass and composition from multiple scientific sources including NASA JPL & Minor Planet Center. With this information, they estimate the costs and rewards of mining asteroids. The asteroids are visualized as a particle system simulation obeying physical laws of gravity and Kepler's orbital motion. The value of the asteroid is mapped to the brightness of the corresponding particle.
- **3D Brain Simulation [10]:** Is a simulation of a 3D biological neural network. The neurons and axons are stored in a 3D obj format that indexes their 3D position and connectivity. The simulation starts by exciting an arbitrary neuron and proceeding to visualize the propagation of the signal through the network with a designated transmission latency and lifecycle.

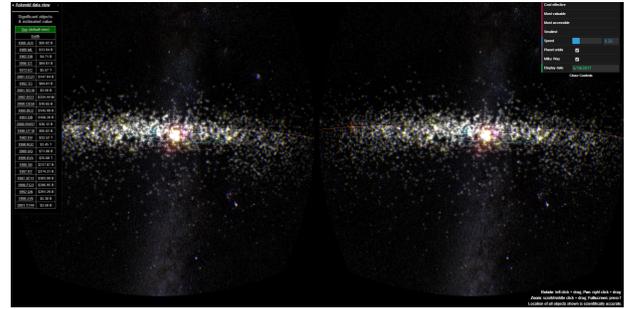


Figure 6. Stereoscopic rendering of Asterank

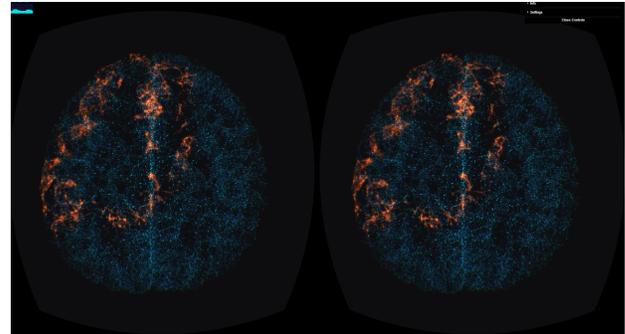


Figure 7. Stereoscopic rendering of the 3D brain network

### RESULTS AND DISCUSSION

Qualitative results of our system are shown in Figures 4, 6 & 7. During a public demonstration of our system we collected anecdotal feedback from users, several of whom were experiencing virtual reality for the first time. The reactions varied from "Wow! This is awesome!" to "This hurts my brain". In general however, most users found the immersive visualizations to be very compelling. Most experienced a certain 'wow' factor that they could not quite pinpoint, but which we hypothesize was a reaction to viewing synthetic data in 3D with a full sense of parallax and scale – something that most people are not used to experiencing regularly. Most users were also proficient at using the brushing and selection tool requiring only very brief (a sentence or two of) training. Selections were precise and users reported that they could select surprisingly small targets with the interaction technique.

We did observe that, for some users, interactions in VR were more challenging. Some users' movements were tentative, since the VR headset blocks vision of the real world. Some users instinctively used the clicking device as a laser pointer type device, although this interaction was not afforded. A user reported "getting lost" in the visualization and suggested the use of landmarks or breadcrumbs to provide context. Another user suggested a "swimming" motion for moving through data, as a more natural feeling interaction. A few users were bothered by the unpleasant visual artifacts such as the screen door effect, judder and lag in the virtual display, but hopefully these will be alleviated as the display technology progresses. Overall we found that interaction in VR is still a challenging problem. Since the view of the real world is obstructed, using traditional input means such as a mouse or keyboard are infeasible.

## FUTURE WORK

Though our preliminary results are promising, there are several avenues for future work. First we would like to integrate our gaze based selection techniques into the WebGL visualizations in order to more effectively interact with the data. We would also like to perform more formal studies to evaluate the effectiveness of both interaction and visualization techniques in VR. It would be interesting to incorporate natural user interface technologies such as Leap motion [9] that tracks the users finger movements and renders them in the virtual scene. Finally, it would be valuable to understand the 3D/VR equivalent of 2D visualization metrics such as data-ink ratio. Perhaps something along the lines of data-neck movement ratio(?).

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