A pandemic's hierarchy through VR

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ABSTRACT
This paper describes our final project for the CS8803 3D User Interfaces Class. The goal of our project is to create a virtual reality user interface to display data from the COVID-19 pandemic. Users will be able to navigate hierarchically organized data that shows the rates of infection per location and region. By leveraging the interactions possible in VR space, our project aims to create a unique visual method to explore large scale hierarchies.

INTRODUCTION
Traditional user interfaces for computers have represented hierarchies by using lists and tables. The first file system UI's displayed their information as a table with each row containing the name of a file, its file-type, size, and last date of modification. While this file-system display has not changed, the interaction methods have moved from command line inputs to mouse or touch selection. Newer filesystems now have options to show a file's location as part of the hierarchy as well as a preview but the fundamental orientation used to display files has not changed.

In regards to menu systems, the 1984 Apple Macintosh popularized the list format for hierarchical menus that exists today, with a horizontal bar at the top of the screen being used to show categories of options. Clicking on any one of the menu options displayed on the top of the bar would reveal a vertical list of further menu options which could either open up a new window or display another list of options to the side of the first list. Virtual and augmented reality present opportunities to use 3D displays and visualizations to ameliorate the presentation of these hierarchies.

The UI methods for hierarchies and menu systems can trace their roots to traditional print mediums and this extends to data visualization. With 2-dimensional mediums, there are constraints on how much data can be represented in a particular chart or graph. Virtual reality presents the opportunity to represent the data in a 3D space that can be physically interacted with and explored. Our goal with this interface is to create a visualization system that uses spheres to represent different locations and data associated with each location, the base unit of our hierarchy. The current COVID-19 Pandemic offers the perfect case study to test this approach for location based data visualization.

ACM ISBN 978-1-4503-2138-9.
DOI: 10.1145/1235

MOTIVATION
Deep hierarchies don't have a standard interface for 3D, such as a menu bar on desktop systems. In complex applications, e.g. image processing, the number of menu items needed to explore all the options often can be presented to the user only as a menu. Menus seem clunky in VR and are a 2D metaphor translated to 3D. 3D metaphors for information hierarchies should utilize the depth available to the user, and we propose a spherical 3D interface to work with such hierarchies. During our research and design on an interface, we realized that data from the ongoing COVID-19 pandemic presented the opportunity to create a complex data model that could describe multiple facets of data at once. Being able to visualize the locations of the data as well as see the rates of change over time allow users to get a better perspective on the current state of the infection.

RELATED WORK
Presenting information hierarchies in a 3D visualization has been explored extensively in literature, especially spherical interfaces. When dealing with information such as networks, or large numbers of images or videos, spheres have often been explored for their usability[4][8][14][20][13][18][16][19]. Immersive applications of said spheres have also been explored[17][3].

Applications with a spherical medium itself, e.g. a spherical screen have also been explored, and while not as versatile as a 3D environment, provide some direction for the development of spherical interfaces[1][2].

Our inspiration and data source for this project was based off of John Hopkins University of Medicine visualization of the COVID-19 pandemic [10]. This visualization represents the cases in 2D over a map and uses flat circles to show rates of infection and other statistics. A variety of data tracking and visualization work can be applied towards disease tracking [6] from infection rates to spatial tracking [7] [9]. These visualizations have used maps, graphs, and other 2D representations to represent data. In these representations, spatial mapping is used to show movement of peoples between regions to preemptively track the spread of infection. This process is known as contact tracing and can be used to prevent further spread of a disease. Not only can this data presentation be used for infection management but it can also be used for public education too help disease prevention measures [11].

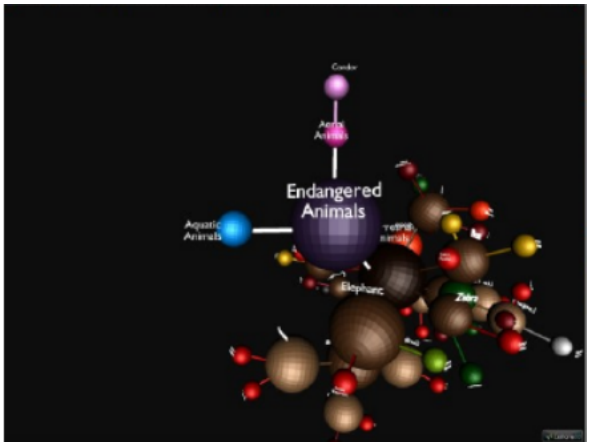

Figure 1. The I-Sphere prototype, an inspiration for our implementation

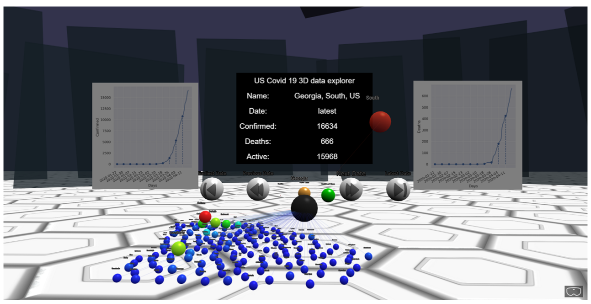

Figure 2. The primary interface of our COVID-19 3D Data Explorer

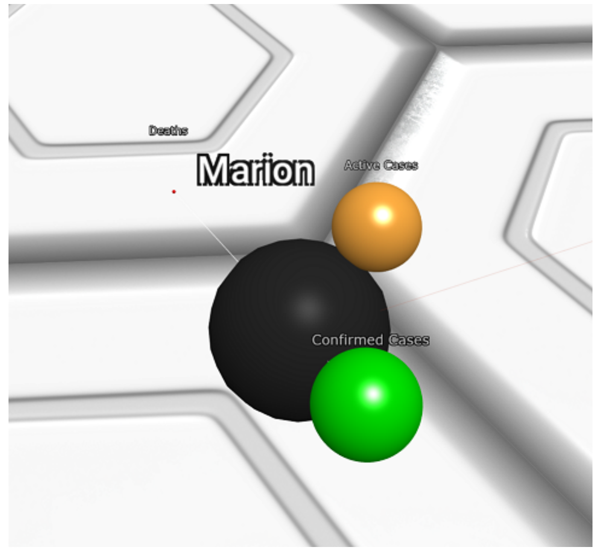

Figure 3. A zoomed view of the statistic children nodes for a particular region

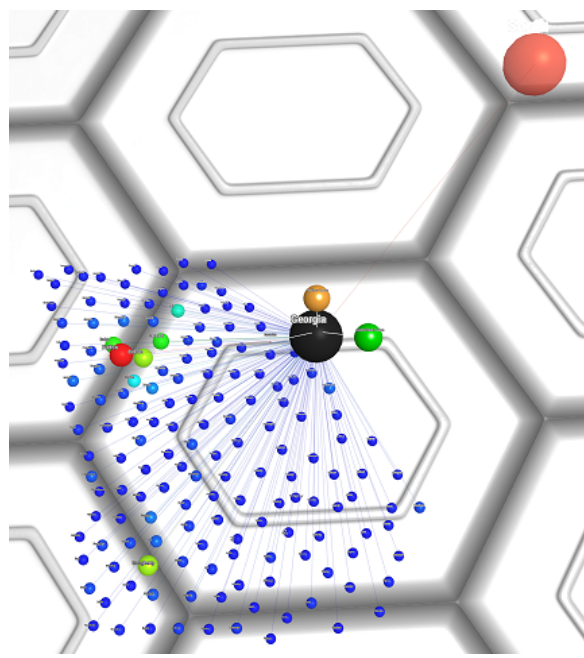

Figure 4. A view of Georgia's region data that shows how the county layout creates a map effect

SYSTEM DESCRIPTION

We were inspired by Cone Trees[15], and the Hololens One Galaxy Explorer[12]. The I-Sphere[5] shown in Fig. 1 is a close approximation of such a system without an immersive interface. It interacts with the user using connected spheres to depict relations between the data. Such interfaces are efficient at presenting to the user large, deep hierarchies in a 3D format. In our implementation, we use an I-Sphere style node to represent a particular location, referred to as a "level". Each level is defined by a parent node, an ancestor node, and two sets of children nodes. The ancestor node corresponds to a node's hierarchical parent such as the region a state is in. The first set of children correspond to sub-regions of a location e.g. counties within a state. By placing the sub-region children in locations that match their relative position within their overall region node, we are able to create a map that can be explored. Each location node is labelled and the overall shape of a region node's sub-region children nodes allow for a state's data to be easily recognizable. We also have controls for exploring data from different days during the pandemic period. Using graphs, we represent the currently selected node's data changes over time.

Our system of displaying this data in 3D provides several challenges:

- **Information available to the user at every stage, and how it is presented.** This will be crucial in determining how comfortable the user is with the menu and how efficiently they can consume the information presented. On the other hand, we risk overwhelming the user with the number of options so a balance needs to be found in the presentation.

- Our interface exclusively uses spheres as interactive buttons, allowing the user to easily familiarize themselves with moving through the different hierarchies and explore the data. Each node is labelled to reduce confusion. We adjust the size of each node's label to ensure that there is ample space for labels on screen. In order to explore further through the hierarchy, children and ancestors are available connected to the parent node in opposing directions.
- **Providing a logical interface for the user to mind map through**. Just like a menu can provide a clear context to where the user is navigating to, our interfaces creates a map-like system that users can more efficiently scroll through it. Familiarity provides affordances to get closer to being an expert.

Apart from these concerns, the interface should be aesthetically pleasing, and we endeavour to make it a natural metaphor akin to a galaxy. We plan to add sound to the interactions so that the experience is a more engaging one and the user has more cues to rely on for the navigational experience.

We have used Babylon.js to program for the Quest, and to create a generic enough system which can be implemented through a JSON file which provides the hierarchy.

IMPLEMENTATION

We chose the COVID-19 outbreak data in the United States as the primary goal of our implementation. This application allowed us to identify the base variables that were important for our system, i.e. the geographical hierarchy, and the time span of the infection. We deal with each of these variables through different interfaces, and allow the user to manipulate the visualization effectively.

Geographical hierarchy

The hierarchy of geography in our application is as follows:

- Country - In our case, the USA
- Region - The US Census regions - Northeast, South, Midwest, West
- State - The states in each region
- County - Counties in each state

Each of these is similar in that it has children nodes which are geographically spread apart, and an ancestor node which lies higher up in the hierarchy. The exceptions are the country and county nodes, which are the limits to the data considered.

The geography provides a way to organize children nodes that users are already familiar with, and allows us to keep the number of nodes to be created and displayed in the scene to a minimum. The total geographical nodes to be created if the entire hierarchy was to be plotted would number 3200, large enough to cause performance issues.

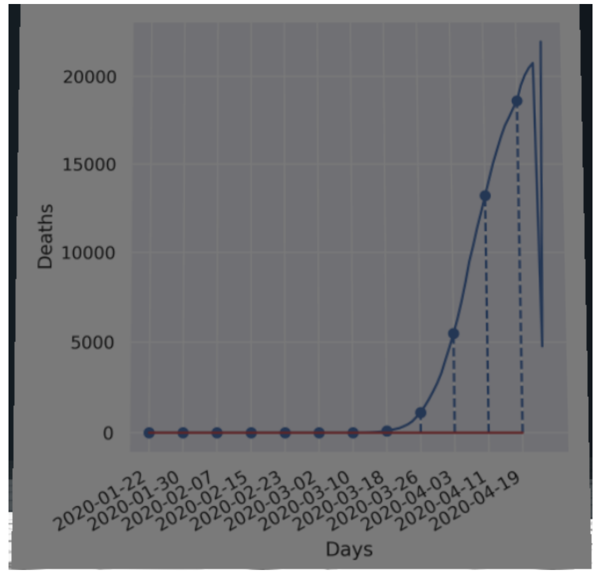

Figure 5. Faults deaths count for New York

These nodes are labelled for context and boil down to their wireframe on hover to provide a strong visual feedback to the user. Navigating through recreates the new level in the same space in front of the user, realigning their context with the new level. New colours and nodes provide the indication the user needs to look at the level switched to.

Changes in geographical hierarchies are also represented through the dashboard and the graphs, which are statically positioned elements in the scene in the background. They provide the context and detailed data about the current node and time to the user.

Dashboard

The dashboard provides the user with:

- The full name identifier for the current node, e.g. Fulton, Georgia, USA
- The current date of the data and visualization
- Confirmed cases in this node
- The number of deaths in this node
- The number of active cases in this node. This is not an exact figure as recovery statistics are only available on a country wide basis. In our case, this number is $confirmed - active$.

Graphs

The graphs provide a time sensitive context for the infection in the region. They auto-adjust on the number of cases, and if $cases > 100,000$, the graph is switched to a logarithmic graph. The graph provides a quick overview of the infection through the entire time span for this nodes. This provides the user with important constraints when navigating through time. They also provide insights into the data collection taken by counties and any lapses that might have taken place are clearly identifiable through them, e.g. Fig. 5.

Time navigation

The adoption of the COVID 19 dataset for our project presented to us the opportunity to use time as an axis to manipulate our visualization. While not our initial goal, it was an interesting aspect to the visualization as it would help provide insight into the history of the spread of the virus.

While we planned for time navigation to be a continuous interface over the dates, the constraints of the environment did not allow us to build such an interface. We chose instead to use 4 navigation buttons akin to pagination on websites to navigate through a large series of dates. The earliest and latest buttons take the user to the beginning and current date of the infection in the US respectively. For the previous and next buttons, we chose a time jump of a week between visualizations to provide an engaging experience through the difference in the relative infection levels for the user.

EVALUATION

Overall, we succeeded in creating a unique 3D visualization for a hierarchical data set. At the time of writing, the COVID-19 pandemic is still ongoing and thus our visualization has a great deal of current relevance. By displaying the data in a 3D format, we have captured the sensation of physically exploring data that traditional data models lack. With further work we would be able to create a dynamic system that could be useful for use cases such as presentations, data analysis, and public education on this current pandemic. We speculate that there is a level of acclimatization that occurs when looking at traditional data visualization mediums that reduces the feeling of scale for a user; with a 3D visualization we aim to provide a resource that can properly convey the scale of the crisis and assist with public directives such as Stay-At-Home measures.

Our initial plan was to create a spatial model of the entire United States - however this would require us to create nodes and additional graphics for over 3000 different regions and counties. We were able to focus on Georgia and New York, with the latter being a major location for COVID-19 infections. However, our attempts to create programmatic graphics for each data point made loading different regions and infection dates much more difficult. The main problem point when it came to further interactions were loading times when moving between different data levels. We found that automating certain aspects such as node labels and maps would decrease the loading times. Our solution was to have these labels generated before hand helped improve loading times but also prevent us from expanding our model to different states and countries. We also could not display a map or a shapefile below the children node for even more user context due to time constraints. Once we are able to properly optimize loading of different levels, we would like add in these features as well as a "play" feature that would show show an advancing time period from the first recorded day of data to the present.

While our final product greatly differs from our initial approach to use spheres to create a basic user interface for a virtual reality operating system, the hierarchical system that we created could be re-purposed for that use case. The ability to create the sensation of physically exploring data lends itself to big data visualizations in VR space, especially data that uses geographic mapping. Currently, we would need to explore physical interactions for our data model before bridging our implementations to different use cases. We also want to explore using different shapes for some of our controls. In particular, the time control system could be improved by using a different interface than spherical nodes, especially a continuous control system.

FUTURE WORK

Our first step towards exploring future interactions for this project would be to optimize the loading of different levels. The current loading times, especially for regions with numerous sub-region children is a major roadblock to some of our proposed improvements. One such improvement is the ability to play through a region's time data by starting from the first recorded data point to the present data points. While currently this might be possible for an individual node's statistic children, we would also like to show changes over time with the sub-region children. Optimizing loading times as well as adding in automated systems for the creation of new nodes allow our current implementation to be used for all regions. While our sub regions nodes effectively create a map of the current region, having an actual map be displayed beneath the sub region nodes would more effectively convey the data as well as help with recognition for locations a user may not be familiar with. In addition, we also aim to explore the idea of peer nodes for a region nodes. One potential idea is having a region's neighboring nodes be displayed on the same horizontal plane as the currently inspected node. With adding more currently visible data, our main concern is to avoid over-crowding the user with too many data points.

Our implementation could also benefit from better transitions between different data levels. The inclusion of physical interactions such as picking and dragging region nodes is an option for selecting and moving between different data locations. However, these physical interactions are not feasible without additional graphical transitions and optimizations. Dynamic labels over a large number of nodes could allow the creation of children dialogs that provide the user with more information which allow them to analyze the visualization more effectively.

The first stage of this implementation has focused on the visual aspect of exploring data in the VR space. Our further goals should include exploring ways to increase the physicality of displaying and interacting with data in a virtual environment, furthering the visual polish and information displayed by the system, and providing smoother load times so that expert users can navigate efficiently through the visualization.

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