Use of spatial audio in immersive analytics

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Declaration of Originality

I, **Akshay Jain**, with SR No. **04-04-00-10-42-16-1-13270** hereby declare that the material presented in the thesis titled

Use of spatial audio in immersive analytics

represents original work carried out by me in the **Department of Computer Science and Automation** at **Indian Institute of Science** during the years **2016-2018**.
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Abstract

In this project, we analyze the use the spatial audio in VR based immersive analytics for large multi-dimensional abstract datasets by creating a complex, dynamic environment for data exploration. Immersive analytics is an emerging research field because of benefits virtual environments are providing, i.e., a large field of view and more natural interaction with the data. However, for large multi-dimensional datasets, it is difficult to analyze the data even inside of an immersive environment because of the complexity of the data and volume of visual information being presented at the same time. We believe that spatial audio can improve the analysis of multi-dimensional datasets within immersive environments and help the user extract the patterns and information from the dataset which would otherwise not be possible.

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Chapter 1

Introduction

We are living in the era of big data. Huge volume of data is being generated every day and we need non-conventional techniques to analyze the data and extract meaningful information from the volume of data. Every organization is using the collected data in one or the other form to make predictions for their decisions and hence influencing everyone around. Multiple techniques are being used to get insights from the data and visualization is one of those techniques in which abstract data is presented in some form so that it can be interpreted by the user. In this chapter we look into the basics of technique of information visualization, then study about VR (Virtual Reality) and the combination of VR with Information Visualization known as Immersive Analytics. Finally we will look at Spatial Audio which is one of the major components of this project.

1.1 Information Visualization

Information visualization has been concerned with representing the abstract data in a form which can be interpreted by the user easily. In a traditional setting, the dataset has been small enough to represent data as bar charts, scatterplots, etc. With the increasing size of data, it became difficult to visualize the data using traditional techniques which lead to finding new ways of visualizing the data but keeping the representation natural enough for the user to be able to understand the extract the information. For example, one of the members of the Wolfram community did a study representing Wikipedia data as a graph. He created the graph where each node of the graph represented the Wikipedia page, and there will be a directed edge between the nodes if there is a link on the first page represented by the first node to the second page represented by the second node. He claimed If you start at a random Wikipedia page, click on the first link in the main body of the article and then iterate; you will (with a probability of over 95% end up at the Wikipedia article on philosophy and visualized the claim

using an interactive representation of the graph.[11]

1.2   Virtual Reality

Virtual reality (VR) is a computer-generated scenario that simulates experience through senses and perception i.e. a virtual environment generated using programming tools to which our senses reacts just like they would the real environment. VR has been a field of study since 1960's but has picked up recently because of current advancements in the computation power in Graphical Processing Units (GPU) and decreasing size of integrated circuits. In 1968, Ivan Sutherland and his student created what is considered to be the first head-mounted display (HMD) system. Currently, VR headsets are available as commercial products for use in homes mostly for the purpose of entertainment and gaming. In recent times, multiple use cases for the headsets are being recognized and different applications of VR are emerging.

Figure 1.1: HTC Vive HMD

1.3   Immersive Analytics

The ability to extract information and patterns with the use of visualization techniques has been a studied very well and is called Visual Analytics. Visual analytics seeks to use information visualization which is the visualization of abstract data and scientific visualization which is the

visualization of real-world data mimicked as closely as possible, along with the computational and analytic processes to provide insights into the data. Work on visual analytics has shown that it can help in mining patterns that were not computationally feasible.[17] However, with more and more data being available every day, it is becoming difficult to visualization techniques which can be helpful in the analysis the data. It is usually difficult to analyze the data on a 2D screen because of the limited field of view and the limited interaction with the computer peripherals. With large datasets and multiple dimensions, we would like to have more natural interaction with the data and also the ability to look at more and more data at the same time to be able to mine patterns and information from the data. We circumvent this limitation by the use of a Head-Mounted display (HMD) based virtual environment for data visualization. Latest HMD based devices like Oculus Rift[6] and HTC Vive[4] offer a high resolution, head tracking, 360-degree exploration and interaction using remote controls which makes them ideal for data visualization as well. This technique of visualizing data for analysis inside of immersive environments is called Immersive Analytics.[13]We built a software as a course project for Virtual Reality and its applications course to visualize the stock market data by representing it as a city where each building represented a company in the stock market. We will explain the project in one of the upcoming sections.

Immersive analytics recently emerged as a research field for many researchers previously involved in Information Visualization and Scientific Visualization. Immersive analytics has seen its applications in many domains like Health Care[24], Finance[10], etc. for information visualization and has been useful in scientific visualization[25] as well. Also, there has been some commercial applications developed for information visualization in VR environment in the recent years.[5][3] In this project, we are focusing on information visualization aspect of immersive analytics, and we will provide further details in the upcoming sections.

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Figure 1.2: Immersive Analytics
(Source: http://immersiveanalytics.net/)

1.4   Spatial Audio

Humans beings are born with the capability to localize and distinguish between sounds. Sound localization refers to the ability to identify the direction and distance of the origin of the sound. The auditory system uses several cues for sound source localization, including time-difference and intensity-difference between both ears, spectral information, timing analysis, and correlation analysis. The two dominant cues in human beings are time-difference and intensity difference between both ears. The audio has always been an important component in the understanding of the surroundings by providing the ability to localize the objects as well as distinguish between different objects and different people just by using the audio. Audio systems work in all possible directions at a time and practically doesnt require any additional component to work like the light is required for the visual system to work. We would like to leverage this existing capability of the humans to help analyze the large datasets. We will be doing this by introducing Spatial Audio with Immersive Analytics. Spatial audio consists of the sound effects which lead to the effect of the presence of objects in the 3D space using headphones by generating appropriate audio cues computationally. Spatial audio has been studied extensively and have practical applications in entertainment industry primarily.[22] We will be looking at the applications of spatial audio in Immersive Analytics. To best of our knowledge, there has not been any work which used spatial audio in the context of information visualization or sci-

entific visualization.

Immersive analytics has been helpful in solving some of the problems that came because of increasing size of data available by adding another dimension to our view. But, as the size of data increases, we need to find new methods of visualization which can help in the analysis of high dimensional datasets. In this project; we will be evaluating the use of spatial audio with immersive analytics to analyze large multi-dimensional abstract datasets. We will do it by implementing one possible application of spatial audio in immersive analytics. Our project is the visualization of the stock market data from 2000 to 2018. Our aim is to show that the spatial audio is helpful in exploration of the data compared to the application without the audio. We presented the application to 5 people and found that the users were able to find more patterns with spatial audio which were not visible without spatial audio.

1.5   Outline of the thesis

In this section, we provide a brief outline of the problems addressed and the organization of each chapter of this thesis.

Chapter 2: Related Work
This chapter will have the details about the related work done in the field of immersive analytics, information visualization, and spatial audio.
Chapter 3: Data
This chapter will have the details about the different datasets considered and the final dataset used in the implementation and various reasons for picking the dataset.
Chapter 4: Implementation
This chapter will deal with all the implementation based details including data sources and algorithms used at various places.
Chapter 5: Experiments
This chapter will list out the experiments performed as part of the project to make the different decisions for the final implementation and will also contain the results of those experiments.
Chapter 6: Challenges
This short chapter will list some of the biggest challenges faced during the implementation of the project.
Chapter 7: User Study
This chapter will have the details about the user study which was conducted to evaluate the useful of spatial audio with immersive analytics. For this the projected to evaluated with and

without the spatial audio. We also present the results of the user study in this chapter.

Chapter 8: Conclusion

This chapter will summarize the details of the project.

Chapter 2

Related Work

As mentioned in the previous section, there has not been any work which considered Spatial Audio and Immersive Analytics together. However, there has been some recent work done in the field of immersive analytics, information visualization, and spatial audio. We have divided this section into four subsections covering each field explaining the prior work done relevant to this project.

2.1 Spatial Audio

Spatial audio is a very well researched topic and is being used in entertainment and gaming industry from a very long time. In this subsection, we will explain some basics of the spatial audio, look at some applications and then point out the findings from the literature that are relevant to this project. [22]

The human brain is capable of identifying the direction of the sound source with at most 10 degrees of error and can predict the distance of the sound source for known sounds with fair accuracy. For computational purposed, In contrast with a visual system where localization means the ability to point out the exact location of the object in the world, sound source localization only deals with the identification of the direction of the sound source.

There are two dominant cues humans auditory system uses to localize the sound Sound intensity difference and sound timing difference between two ears. In case of the sound intensity, the brain can deduce the direction of the sound with the help of difference in sound intensity of left and right ear which is known as Interaural Intensity Difference (IID). Similarly, for time difference the brain deduces the direction of sound with the help of the time difference the same sound reaches the right and ear and is called Interaural Time Difference (ITD). The audio cues used to localize the sound and include two ears are called binaural cues.

It is quite clear that with binaural cues, a sound coming from the front of the user or back of the user will generate the same cues and makes it difficult for the user to identify the direction from front and back. This phenomenon is known as Front-back confusion. Monoaural spectral cues are usually used for vertical localization and resolving front-back confusion, but in this project, we do not focus on monoaural cues.

One of the important factors in the audio signal that reaches the brain is Head Related Transfer Function (HRTF). A head-related transfer function (HRTF) is a response that characterizes how an ear receives a sound from a point in space. As sound strikes the listener, the size and shape of the head, ears, ear canal, density of the head, size and shape of nasal and oral cavities, all transform the sound and affect how it is perceived, boosting some frequencies and attenuating others.[7] Audio that is not processed through HRTF appropriately will not allow the user to localize the sound source and hence it is required to have the spatial audio processed through the HRTF before it is transmitted to the user through headphones. HRTF poses some challenges in generating spatial audio which we will describe in a later section.

Spatial audio has its applications mainly in the entertainment industry which consists of gaming, movie and music industry. Gaming is the first choice of application for spatial audio because we already have the coordinates of the sound sources available to us and spatial sound in gaming can significantly improve the user experience. In movie and music industry, it is used to simulate the 3D surround sound using headphones which have been generated by using multiple speakers so far. Now with improvements in virtual reality and augmented reality technology, it is being used to improve the user experience inside of immersive environments. But so far, even in immersive environments, it has been used mostly for gaming and 360-degree videos, and we will be looking at the use of spatial audio for information visualization[20] Here are some of the relevant and significant observations from the existing literature.

1. Binaural cues help in localizing the sound source in the horizontal plane only. Having the sound sources at different vertical positions in the virtual environment will make it difficult to identify the source direction in a horizontal plane as well.

2. The direction of audio is determined by the intensity difference for high frequencies (more than 1600 Hz) and time difference for low frequencies (Less than 800 Hz). For the frequencies in the range, 800-1600 Hz both intensity and time difference together help in localizing the audio source. For the virtual environment, having the high frequency is better as creating the time difference is difficult by computational methods. The frequency range for most effective sound source localization is 8-9 kHz.

3. There will always be errors while perceiving the direction in the virtual environment and so some other cue has to be provided apart from audio (visual most likely) to ensure that the direction is perceived with least error possible.

4. The audio clip should be long enough to be able to change the audio dynamically when the head is rotated in some direction. Moreover, so, the extended audio clip will help in localization quickly and correctly and helps in dealing with front-back confusion as well.

2.2   Auditory Icons

Auditory icons are the short sounds which are meant to convey the occurrence of a specific event or some other information. For example, the trash can sound that is played by the common operating systems when the user performs the action of deleting a file to convey the success of the performed operation. Similarly, a beep is played whenever user performs an illegal action which can not be completed. The auditory icon might indicate some other parameters as well, for example, the type of file deleted when the file delete action is successful. In general, the sounds that are used with the auditory icons are the sounds that we hear in daily life so as to make the inference obvious to even the first time users just like the trash can sound. But this is not a rule of thumb and sometimes new sounds are created and used expecting that the user will eventually learn the meaning of that sound. These kind of audio icons which are the expected by the users to be understood from daily life are also called Earcons. The other most common type of audio icons are created by recording the speech audio and shortening the duration of the audio by multiple times. Experiments show that those kinds of icons are very useful in the scenarios where some kind of abstract event information is being conveyed. [16] [26]

Auditory Icons were traditionally used in Auditory interfaces which are similar to visual interfaces created using the Audio only. Just like icons are to visual interfaces representing some information, auditory icons are to auditory interfaces. The kind of information represented by audio icons and visual icons can differ significantly but both of them are crucial to the interface design. Currently, both audio icons and visual icons are used together to represent different kinds of information in the interface which is the combination of both visual and auditory interfaces.

Some of the most common usages of audio icons are:

- about previous and possible interactions,

- indicating ongoing processes and modes,

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- useful for navigation, and

- to support collaboration

There are many new use cases of auditory icons coming up with new applications. Auditory icons have many applications and also some challenges while using them. Here are some of the challenges:

- Mapping: How should sounds be mapped to events? The different sorts of mapping from perceptible representations to underlying events.

- Vocabulary: What sounds should be used? Is hearing a telephone an example of everyday listening? How can sounds be both recognizable and discriminable?

- Annoyance: How can we use sounds without driving users crazy?

In this project, we will also use the auditory icons to indicate the occurrence of certain events in our data visualization. We will combine auditory icons and spatial audio to convey more information than just the occurrence of the event providing the user with more details for exploration of the data.

2.3   Immersive Analytics

Immersive analytics is a relatively new area of study and has been started to grow in the recent years with the growth of VR based technologies and devices. Here we will discuss some of the techniques that are used for information visualization in immersive environments and then look at some of the existing work using those techniques.

2.3.0.1   Information Visualization Techniques

Existing work on immersive analytics shows some common kinds of techniques employed for different applications. Here we will explain some of the most common techniques we looked at, and in the next section, we will look into some specific applications created using these techniques.

1. Data Slicing Data slicing is one of the most common techniques used in information and scientific visualization. Data slicing deals with slicing the data in a particular direction to view the filtered data at the low level of detail. We explain two examples of data slicing in the VR environment.

2. Geophysical data Data related to geophysical properties and events are of interest to many people in VR because of the nature of the data that allows the user to connect to the real world from within the visualization.

3. Traditional forms of visualization Some of the existing work tried to improve on the existing forms of visualization by porting the techniques like charts, scatter-plots, etc. to the immersive environment to leverage the benefits VR has to offer.

2.4   Existing Systems

Although Immersive Analytics is a relatively new area, there have been some systems created for data visualization for different applications. We will now look at some of the existing systems using the techniques mentioned in the previous sections. Apart from these generic methods of visualization, we found some papers which are different approaches from the usual methods and we think are worth mentioning.

1. Slice WIM[14] - Slice WIM is an example of visualization using the slicing technique. Slice WIM a framework for analyzing volumetric datasets in the virtual environment. The virtual environment consists of a set of two display surfaces: an interactive multi-touch table, and a stereoscopic display wall. Slice WIM helps in analyzing the dataset by allowing the slicing of the volumetric dataset using the multi-touch table and viewing the results on the display wall. The drawback of this system is that even though the interaction is being made through touch table, the visualization is presented on the display wall and hence It will suffer from the drawbacks we faced with the traditional computer screens.
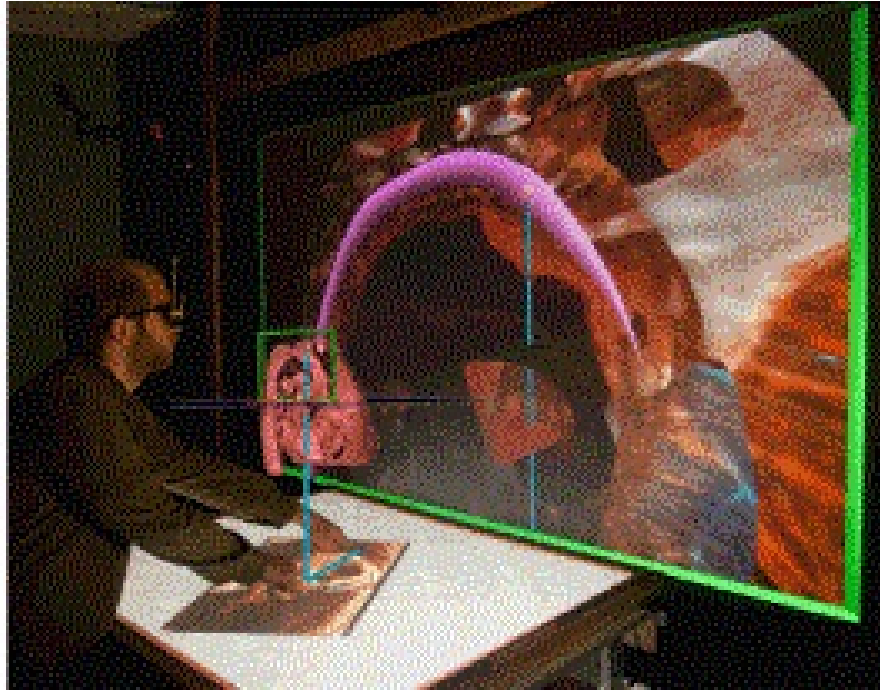
Figure 2.1: SliceWIM

2. Spatial Interaction for the Post-Processing of 3D CFD Datasets[23] - This is another example of data slicing visualization being used to analyze the Computational Fluid Dynamic (CFD) datasets inside VR environment. Authors are using a tablet to determine the position of the slice and also to interact with the data. Authors have placed multiple markers around the observation area and are using the camera of the tablet to determine the direction by identifying the marker present in the direction of the camera. They have used Vuforia toolkit[9] to detect the positions of the markers.

3. Immersive visualization of geophysical data[12] - This paper targets at visualizing the geophysical data by generating the geometry of on the fly with the use of Data Elevation Model (DEM) dataset. Being present at a location and then able to see the geophysical properties of the region is the primary aim of the paper.

4. GraSp[19] - - This paper focuses on connecting two devices: a display wall and a mobile device to visualize the data interactively. The data is being visualized on the wall which is visible to everyone present in the discussion, and along with it, every individual also carries a smartphone connected which can be used to interact with the data on the display wall. They can either look at the data in more details on their smartphone or move the data around on the display wall for everyone else to see as well.

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Figure 2.2: GraSp

5. CAVEvis[18] - Simple visualization of scalar and vector fields using the existing techniques in the cave environment. They have distributed the task of generating geometry and displaying into different modules, and the CAVEvis only reads the geometry generated by the other module. Authors say that the processing everything at one place reduces the frame rate below the acceptable for VR devices which is 20 fps as they mentioned. So, one of the modules generates the geometry and streams to the other module for visualization to parallelize the tasks and keep the rendering at the highest frame rate possible.

6. ImAxes[15] ImAxes is an immersive system for exploring multivariate data using fluid, modeless interaction. By modeless, they mean that no menu and options are presented to the user, and instead of a different kind of visualizations are presented to the user depending on the interaction of the user. The primary interface element is an embodied data axis. The user can manipulate these axes like physical objects in the immersive environment and combine them into sophisticated visualizations. The type of visualization that appears depends on the proximity and relative orientation of the axes with respect to one another, which has been described in the paper by a formal grammar.
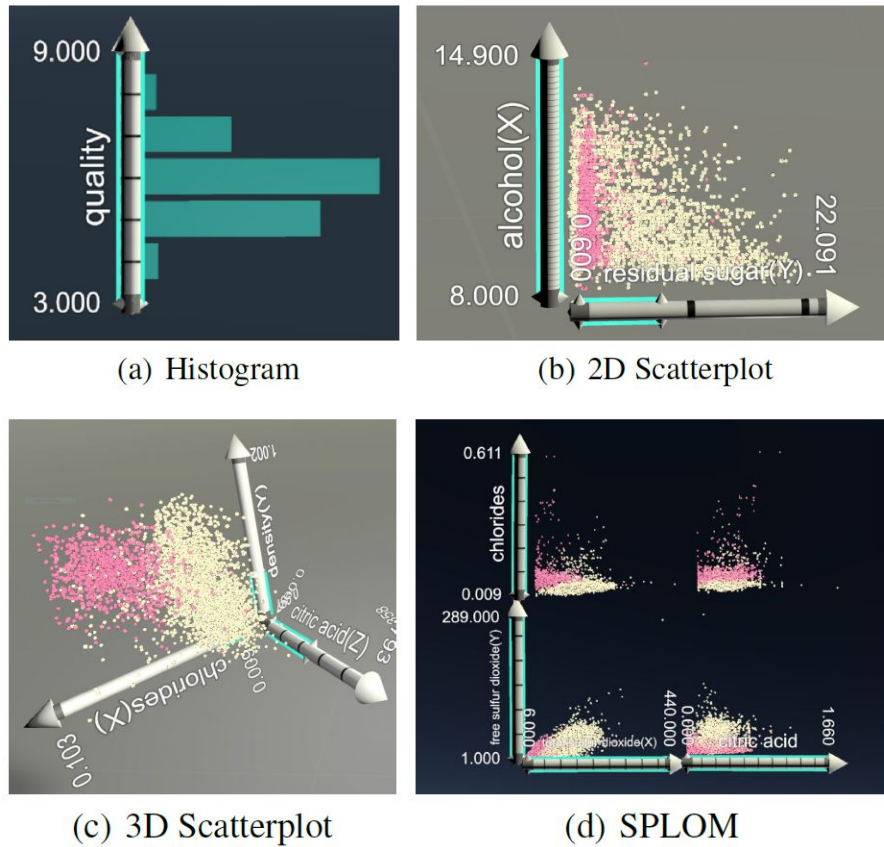
Figure 2.3: ImAxes

Although immersive analytics has helped in visualizing large datasets with the ease and benefits of the virtual environment, it has a significant drawback that it is difficult for the user to understand the direction where to look. As an example, in the case the platform offers some automated data mining as well we would like to have the users attention at the point of interest. Otherwise, the user will not be able to capture the vital information the platform has to offer. Similar kind of problem has also been faced with the 360-videos and has been worked on in the past by providing the visual cues like directional arrows in the current view of the user or by automatically moving the field of view of the user in the direction of interest[21]. In our application, we try to solve this problem by using spatial audio to navigate the users attention towards the points of interest by providing binaural cues in the form of spatial audio and also some small non-invasive visual cues along with the audio. Using spatial audio will not clutter the view of the user so that he can focus on the important information presented on the screen and also can choose to ignore the notification if the user is not interested in the kind of information being presented to him. And so will help the user in extracting more information by focusing on essential and relevant parts of the data.

Chapter 3

Data

Dataset was one of the important factors in deciding the application that we will build. As mentioned before, we want to evaluate the system with a large multi-dimensional abstract data. We looked at many datasets that are available publically and satisfy the requirements. Some of the datasets that we took into consideration are:

1. Sensors dataset One of the datasets that were available to us was sensors data. Simulated sensors data was made available by the CPDM department. The possible application for the dataset was to visualize the data and figure out the reason for some event.

2. Geospatial data As some other papers did as well, we considered geospatial data that is available publically. We considered similar kind of applications as sensors data, ability to reason about a natural disaster given the data before and after the disaster.

3. Satellite image data A good amount of free satellite image data was available with Copernicus-masters. The data has seen many practical applications from the challenges hosted by the organization. The drawback was image processing techniques were required to extract the data from the images and then visualize the extracted data, in which there is a possibility of missing out on some relevant data from the images itself[2] .

4. Social Media data After looking at some of the papers, we considered Social media data like Twitter as well. Getting historical social media data for public use is difficult.

5. Economic data Finally we looked into economic datasets and found most of the clean datasets available are paid, and then we decided to look into the stock market data. We considered stock data for our project as the historical data was available freely and with some efforts could be downloaded. Stock market data has always been of interest to many

researchers, and individuals and firms associated with the stock market. Stock market data was downloaded using an API for the companies whose IPO year was before the year 2000 so that we can have large enough data. Stock data was able to satisfy all the requirements of the dataset we considered, i.e., it is large, multidimensional and abstract.

We decided to use the stock market data for our project and considered applications like finding the correlation between the attributes of the stock market, correlation between multiple companies and multiple sectors, and looking into the data for important events in the history. After deciding the dataset finally, we went ahead and started out with the experimentation phase.

Chapter 4

Implementation

This chapter will have all the details related to implementation and experiments performed so far. We will explain the software platform and environment being used for the implementation, the procedure to download the dataset, and finally look into the experiments that we have performed.

4.1 Environment

Here we explain the project we built for performing experiments and also the specifications of the platform being used for implementation.

4.1.1 Project

For performing experiments, we extend on the project named "StockScape" that was built as one of the course projects for "Virtual Reality & its applications" course. StockScape is an information visualization technique which maps the current stock market data into a virtual city in which you can navigate around and have a look at the information available. The visualization is done by representing a company in the stock market by a building in the city and mapping different attributes of the company with different physical attributes of the buildings in the city as represented in the images.
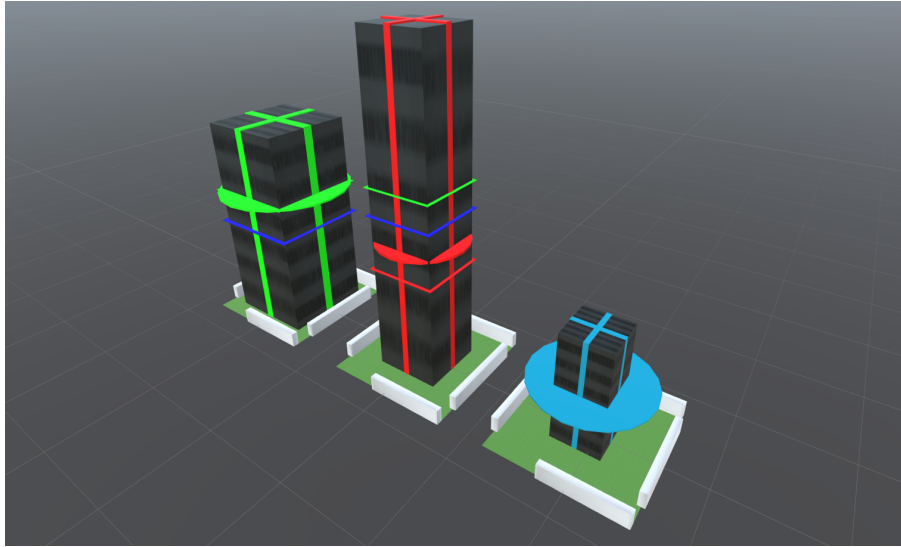
Figure 4.1: Buildings in the project represent a company in the stock market and physical attributes of the building like height, base area, etc.
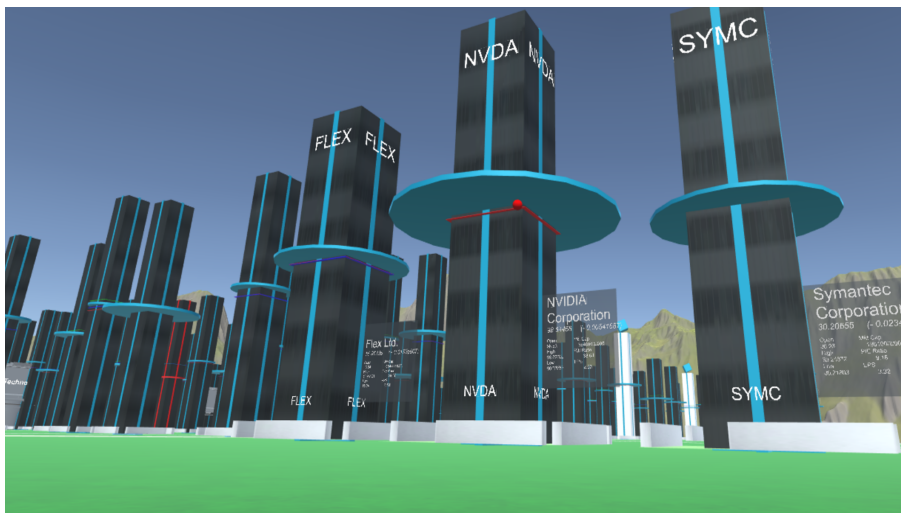

Figure 4.2: StockScape consists of many of those buildings and user is free to navigate around using the controllers and find the answers to queries of user's interest.

We chose to represent the data by a city as people are familiar with the cities and feel comfortable naturally. One of the other possible ideas that we explored was to have a forest representing the data where each tree can represent a company in the stock market. We went ahead with the city because the target user base of the application is more likely to be familiar with cities than with the forest. The complete mapping of stock attributes to the physical attributes of the building is given:

Stock column	Physical Attribute
Price	Height of building
Market Capitalization	Base Area
Price Change	Color of building

Table 4.1: Stock attributes to physical attributes mapping

The color of the buildings correspond to:

Change	Color
Slight Price Increase	Green
Slight Price Decrease	Red
Price Increase above threshold	Yellow
Price Decrease above threshold	Magenta

Table 4.2: Stock attributes to physical attributes mapping

4.1.2 Platform

For the implementation and experimentation, we are using Unity3D which is a well-known gaming engine. The reason behind using Unity3D[8] is the ability to handle the large volume of data, use of best algorithms to render the scene smoothly, and the layer of abstraction it provides making many tasks easier. For the device, we are using HTC Vive having included the motion tracking sensors and also the remote controllers. The specifications of the system that is being used for implementation are:

- Operating System - Windows 10 Pro x64

- Processor - Intel Core i5-4590 @ 3.30 GHz

- RAM - 16 GB

- GPU - NVIDIA GTX 1060 6 GB

The environment had following softwares/tools installed:

- Vive setup - The application shipped with HTC Vive which includes the required drivers.

- Unity - The unity editor was being upgraded to the latest version whenever released. The major update was from Unity 5 to Unity 2018. For the project, none of the changes were required to support the new version.

Along with these softwares, we used the following extensions from the store:

- SteamVR extension: This is the core extension used to make applications for HTC Vive and is being provided by Valve. The extension was being upgraded whenever available. Latest version being used and checked for compatibility is 1.2.3.

- MessagePack-CSharp 1.7.3: This extension is the C# wrapper for the MessagePack library and is used to serialize and deserialize data faster than the .NET library.

- Steam3D-Audio extension: This extension is used to convert normal audio to spatial audio and is built into the unity and gets the update with the update in Unity.

4.2 Data

The main sources available for downloading stock data was Yahoo Finance! But the API has not been made available for Yahoo for the public use. Alpha Vantage[1] offers a free API which has the stock prices of the companys intra-day data after the year 2000. A small script was able to download the data for the companies required in the CSV format. Initial application was taking most of the time in loading the CSV files into the RAM. be In order to improve the performance of the data load, instead of reading the data from the CSV file every time the application runs, the data structure which was created to hold the data at runtime was serialized and saved in the permanent storage after loading the application for the first time and de-serialized to recreate the data structure the application is launched every time. The data has to be directly loaded from the CSV files whenever there is any change the data structure being built. For the purpose of serialization and de-serialization, the first algorithm that was attempted was the default C# library serialization and de-serialization using XML. XML turned out be very slow and after trying out few other libraries MessagePack library turned out to be the fastest and could work with complex data structures easily. The application was able to load the data from the CSV files directly in around 125 seconds and loading the de-serializing data with MessagePack reduced the time to 4 seconds.

4.3 Squarified TreeMap algorithm

The placement of buildings in the city created was an important factor in the navigation user experience. The City is first divided into sectors which were provided by NASDAQ by the

roads to make the clear distinction between the companies of different sectors while exploration. Within a sector we wanted to place the buildings such that they do not colloid with each other and the bigger comapnies (based on Market Capitalization) stay closer to each other. The Squarified TreeMap algorithm was used to Divide the city into sectors and also to place the buildings within a sector. The input given to the algorithms was the base area of all the buildings within the sector and the coordinates of the top left corner and the bottom right corner for the given sector. The algorithm returns the coordinates for placing the buildings inside of the sector. To make sure that the sufficient space is present between the buildings the area of the buildings (Which is also the market capitalization) was doubled before giving it as input to the algorithm.

4.4   Spatial Audio

The main aim was to evaluate the spatial audio with the information visualization. In our project, we used spatial audio for three events which generate different earcons as well. The tree events and the earcons associated are:

Event	Sound
IPO	Whoosh sound like something appeared
Price Increase	Bell ring like music
Price Decrease	Crash sound

Table 4.3: Mapping of events with the earcon

The price increase and decrease events occur only when the price has increase or decreased above a threshold.

Chapter 5

Experiments

At the beginning of this phase, we started with some literature survey and performed little experiments to find out the capabilities of the spatial audio extensions present in Unity3D. This lead to the observations explained in the previous sections that is relevant to this project. We have decided to use the SteamAudio extension available for the project. After this we started doing some experimentation with audio and immersive analytics combined and figured out some of the challenges in integrating spatial audio with Immersive Analytics and are explained in the next subsection.

Here, we will explain the three experiments performed and the conclusions inferred from the experiments -

1. Sound Localization - First Experiment that was performed was to evaluate the SteamAudio extension in Unity3D used to generate spatial audio. A simple project was created with eight audio sources being aligned in a grid at 45 degrees apart. A small low-frequency audio clip was used by the audio sources and played randomly for the user, and the task for the user was to identify the direction of the sound from the eight directions. After this experimentation, we realized the issue of Front-back confusion and also further literature survey suggested the use of high-frequency audio.

2. Spatial Audio Integration - StockScape project was extended further to include the spatial audio whenever there is an event that occurs. This experiment was performed as an early evaluation of the integration of spatial audio to navigate the user attention to the points of interest. In our experiment, the building will create a sound whenever the stock price of the company increases by more than 0.5% since the opening of the stock exchange. This experiment leads to the issue of chaos in spatial audio and multiple audios together or in quick succession made it difficult to infer the direction of the sound.

3. City Arrangement - One of the other decision was to choose the arrange of the city, and we considered two of the arrangements initially grid and circular. We thought of pros and cons of both the implementation and went ahead with grid because of comparable pros and the ease of implementation.

4. Navigation -This experiment was conducted to figure out what kind of navigation in VR environment is most suitable. We found three of the most common navigation techniques Fly, Drive, and Teleport. We tried the techniques and felt that the driving mode of navigation felt most natural, but it also depends on the kind of application in consideration and so all modes of navigation are open for now.

5. Controllers - Controllers are an important part of user experience. The mapping of controller keys to actions was done by A/B testing i.e. by giving users the different set of controls and asking them to provide the feedback on the ease and usage of controls. There are two controllers included with HtC Vive as shown in the image. The left controller was assigned to tasks related to simulation which will be explained in the upcoming section and the right controller is assigned to tasks related to the navigation and exploration. The final mapping decided based on the input from the users:

Key	Action
Trigger	Start/Pause Simulation
Touchpad Up	Increase Speed of Simulation
Touchpad Down	Decrease Speed of Simulation
Touchpad Left	Decrease Step Size of Simulation
Touchpad Right	Increase Step Size of Simulation

Table 5.1: Left controller mapping - Simulation Controls

Key	Action
Trigger	See details of the selected company
Touchpad Up	Move Forward
Touchpad Down	Move Backward
Touchpad Left	Move data date backward
Touchpad Right	Move data date forward

Table 5.2: Right controller mapping - Navigation and Exploration

Figure 5.1: Controls

6. Simulation Choices - There were two choices that had to be made in regards to the step size and the speed of the simulation. For the step size different choices were made like data for every day, week, month etc. The final choice was to give user the option to choose from daily, weekly, fortnightly, monthly, quarterly, biannually, yearly data and change the step size while the simulation is running. Another option was the speed of the simulation. When the simulation is running the dates change automatically and the duration between data change can be changed by the user. Apart from that the ability to pause the simulation and move date forward and backward manually while the simulation is paused was also found important.
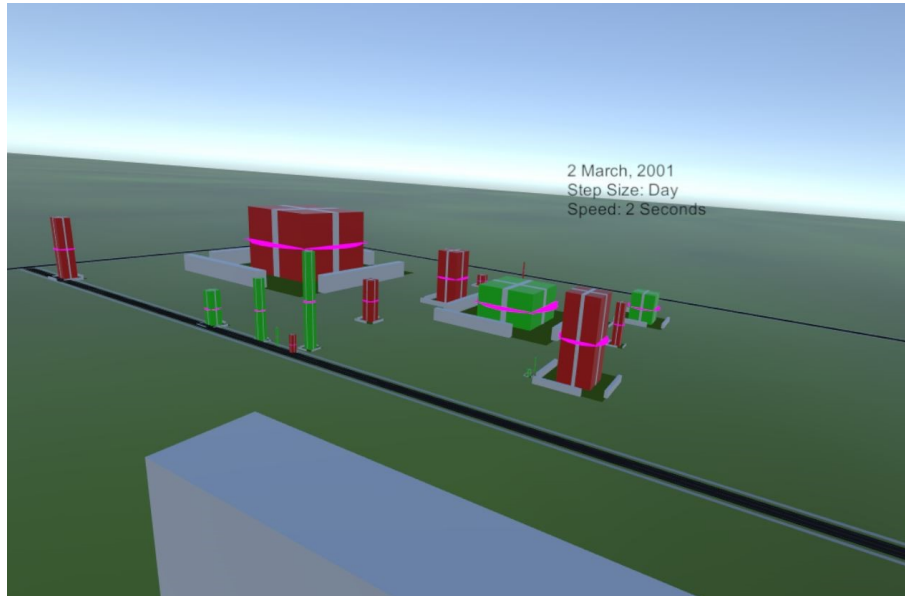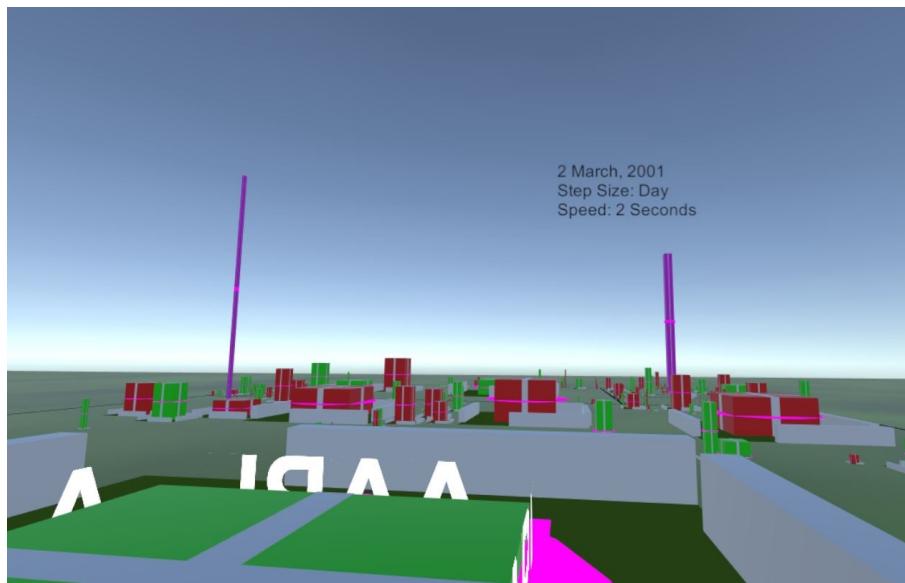
Figure 5.2: View of the sector

Figure 5.3: Magenta buildings represent the crashing stocks

Chapter 6

Challenges

Although we can navigate the user into the desired direction by providing the audio cues but integrating spatial audio with Immersive Analytics has some challenges. Some of the challenges that we face are:

1. Front-back confusion In the field of spatial audio, Front-back confusion is one of the most common problems, and the issue is fixed mostly by providing the audio cue to be long enough that will change when the head is turned around. But having a long audio cue will give rise to other challenges. [20]

2. HRTF is different for everyone We described HRTF in section 2.1 and how it is different for every individual. Many techniques have been developed to calibrate the spatial audio for an individual, but it continues to be a hard task to implement in practical systems.

3. Chaos Depending on the application, having too many audios play together might deteriorate the ability of the user to localize the sounds and a fair amount of experimentation is required to control the chaos of spatial sounds.

Chapter 7

User Study

7.1 User Study

For evaluating the usefulness of spatial audio in the context of our application StockScape. We chose some specific events and asked people to try the application without Spatial Audio and try to see those events and then with Spatial Audio.

The basic events that we considered were:

- The 2001-2002 Crash

- The 2008 Bubble Burst

We guided users to find these events using the application and recorded the observation on how easily users were able to find out the occurrence of the events with and without spatial audio. We did this user study with 5 people. Most of the users are not familiar with the basics of stock market.

7.2 Results

After the user study we found out the users were able to find out the occurrence of the events more easily when spatial audio is present. The analysis was guided and were given instructions on how to choose the parameters and how to understand the data. Here are the details of the whole user study.

7.2.1 2001-2002 Crash

Users were able to identify the crash which corresponded to too many crash sounds coming simultaneously. Which was followed by analysis of the crash. Most of the users found that the

crash occurred during the initial months of the year 2002 and Finance and Technology were the two sectors that the crash started with and impacted the most. The users were able to identify the months of crash with the spatial audio and to see the sectors getting impacted the most they were instructed to move to a top view and see the sectors having maximum crashes.

7.2.2 The 2008 Bubble Burst

This was similar to the 2001-2002 crash and this time some users said Finance sector to be effected the most but most of the users did not see any specific sector getting effected more than the other sectors. And some of the users said April-May 2008 to have the most impact and some users mentioned October to be the period of the most impact.

Chapter 8

Conclusion

8.1 Conclusion

In this project, our main aim was to add spatial audio to immersive analytics and see if the spatial audio improves the ability to find patterns in the data. We performed quite a lot of experiments involving immersive analytics visualizations, controllers, and some other user experience based tests.

We chose the stock market data as our main dataset because of its easy availability and people's interest in the dataset. This project was built as a prototype to show the usefulness of spatial audio in the immersive analytics.

We believe that adding spatial audio has been helpful in our application and there are multiple visualizations in which adding spatial audio for different events can be a significant improvement and will help in exploration of large datasets from within the VR application. This is just the surface and there can be many more applications of spatial audio with the visualization including scientific visualization and information visualization.

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