Combining Virtual Reality and Narrative Visualisation to Persuade

Jim Bastiras

A thesis submitted for the Degree of
Bachelor of Computer Science (Honours)

Supervisor:
Prof.
Bruce H. Thomas, Ph.D.

Adelaide, South Australia
October 2016

Wearable Computer Lab
School of Computer and Information Science
Division of Information Technology, Engineering,
and the Environment
University of South Australia

Declaration

I declare that:

- this thesis presents work carried out by me and does not incorporate, without acknowledgment, any material previously submitted for a degree or diploma in any university;
- to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text; and all substantive contributions by others to the work presented, including jointly authored publications, is clearly acknowledged.

Jim Bastiras - Adelaide, October 2016

Acknowledgements

I would like to thank my honours supervisor, Prof. Bruce Thomas. His support and guidance made this project possible. Without his ongoing encouragement, I would have lost my mind half way through. Similarly, I owe any success I may obtain to all of the members of the Wearable Computer Lab who consistently responded to my requests for help and guiding me through this difficult process. Specific praise must be given to both James Baumeister and James Walsh. Without their patience and help are the only reasons I have accurate results and a finished thesis. I also would like to extend a big thank you to everyone who took time to complete my study and give me feedback, without them none of this would be possible. Finally, I am extremely grateful to me family and friends for putting up with my continual whining and for never getting tired of hearing about my work.

Abstract

This dissertation presents a technique for the design of narrative visualisations that represent complicated datasets using data visualisation techniques. These visualisations are enhanced with narrative elements to create more engaging, emotionally provocative visualisations.

The rise of big data and the open sourcing of large datasets has put more pressure than ever on data science to come up with new ways to visualise and represent these data sets. Data visualisations struggle to handle the often complicated, multifaceted data sets and lack the level of interaction and manipulation required for difficult decision making and data analysis. One solution to this is to introduce narrative theory techniques to help the user or viewer to relate to information and trigger an emotional reaction. These visualisations enhanced, with storytelling elements are called narrative visualisations.

This paper combines narrative visualisations with modern 3-D virtual reality technology to create an effective and focused presentation that persuades the user of a given theory or opinion. This paper aims to show that using virtual reality creates a more pleasing experience and allows a more powerful connection to be made between the user and the information. A user study was run to test these techniques. In the user study thirty people explored a 3D space with data and narrative visualisations placed inside. The users were split into two groups, one group using a normal desktop display and the other using a HTC Vive virtual reality headset and controllers.

The study showed that the users behaviours were not significantly different when comparing desktop and virtual reality. However, answers given by the participants through an end of study questionnaire showed that users felt that the virtual reality did in fact add to the overall experience. This was echoed in ad hoc discussions with the users, those who experienced it through VR claimed to be more engaged and found the experience more enjoyable. Further work into expanding the study and adding more complex data structures for the visualisations could reveal more concrete results.

Table of Contents

List of Figures

List of Tables

Chapter 1 – Introduction

Virtual Reality (VR), as defined by F.P. Brooks [1], is "any [experience] in which the user is effectively immersed in a responsive virtual world. This implies the user [has] dynamic control of the viewpoint". Put simply, VR is the attempt to create a real experience, whether it be realistic or feel real despite of its lack of reality, through immersive virtual worlds. The field of virtual reality has continued to grow and gain popularity through its peak of hype in 1994 [1] to its resurgence today as an entertainment system. While VR has continued to gain popularity and the technology has advanced, computer scientists have continually attempted to find new fields to apply in VR. Virtual reality incorporates the extreme right of the Mixed Reality field (Figure 1)

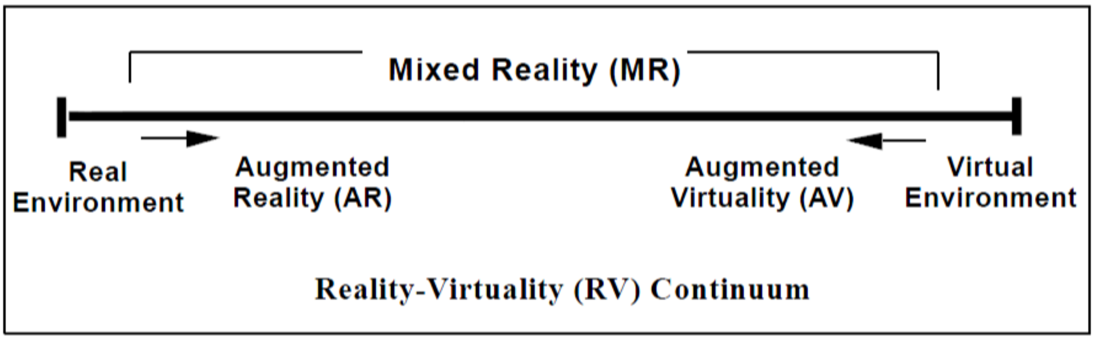

Figure 1 The Reality to Virtuality Continuum [2]
(Image courtesy of Paul Milgram)

Data visualisations is the field in which attempts are made to represent complex datasets, with varying size and structure, in a way that is understandable and visually clear. Data visualisation is an extension of visualisation, which is defined in the Oxford Dictionary as "1. Form a mental image of; imagine. 2. Make (something) visible to the eye", and focuses on mathematical and scientific data. Challenges in data visualisation arise from the inherent problems set upon researchers from Big Data. The information age has led to massive quantities of information being shared and stored on the web and data visualisation has been tasked to find methods of representing all this data. Despite big data becoming an ever-expanding area of research data visualisation still struggles to represent these massive datasets in a way that can allow for insights to be drawn and understanding to be gained.

Narrative Visualisation, the incorporation of storytelling elements seen in other mediums like film and theatre, is a subset of visualisations that aim to aid with the comprehension of massive datasets by representing the data in a more compelling and empathetic way. If a data visualisation is the combination of visualisation and data, then narrative visualisation is the combination of data visualisation and storytelling (Figure 2). Narrative visualisation was first coined by E. Segel and J. Heer [3] in their paper "Telling Stories with Data" as incorporating the strengths of current narrative trends, which have been developed for thousands of years throughout human existence, and applying them to the field of data visualisation. By applying these narrative techniques, it is hoped that more intricate stories can be told and therefore more complex data can be represented.

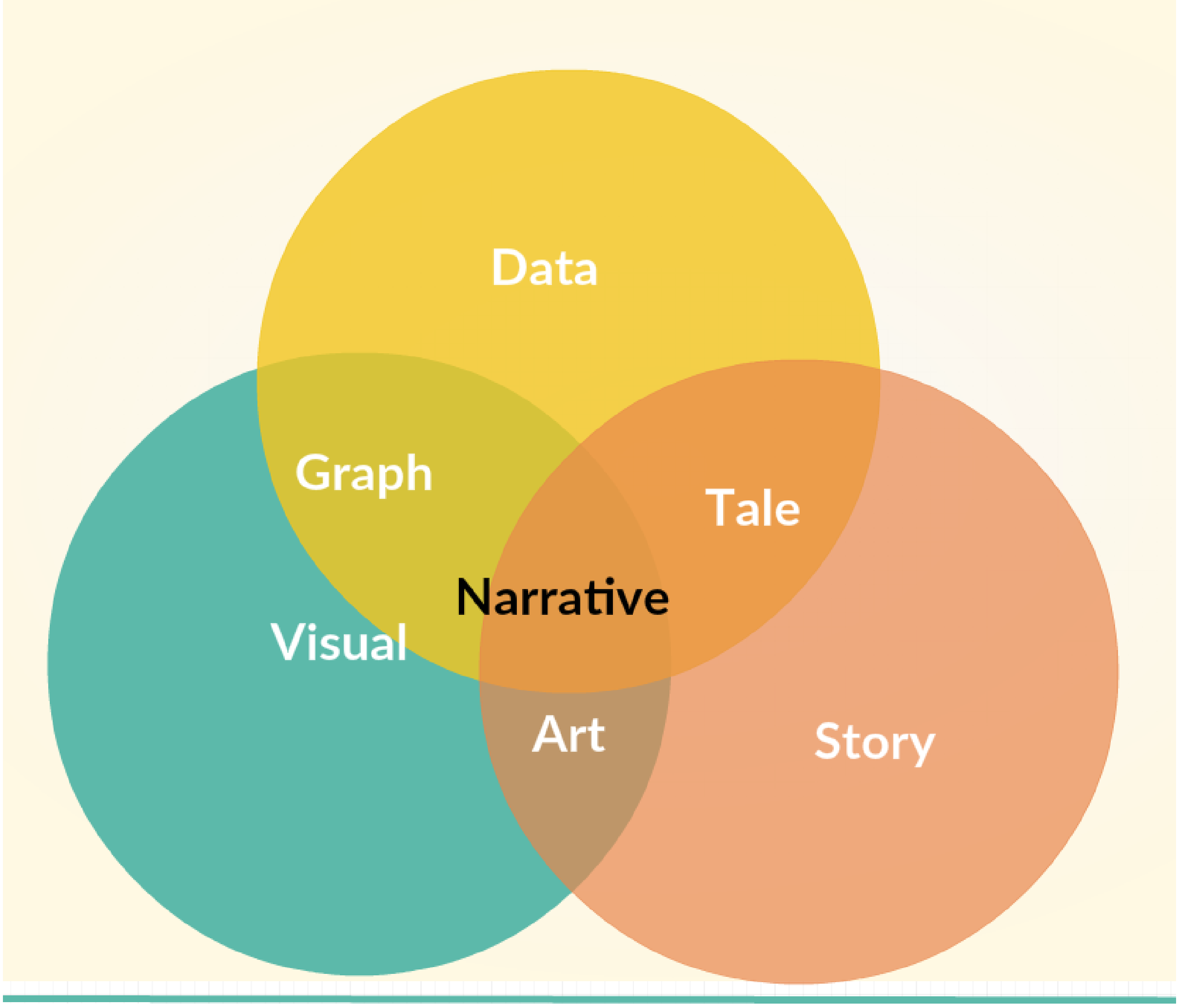

Figure 2 Venn Diagram showing Narrative Visualisation as the combination of Visualisation, Story, and Data

Chapter 1.1 – Motivation

Distinguishing a data visualisation from a visualisation that incorporates narrative elements can be difficult as neither of the two fields have an agreed upon set of characteristics that are wholly

unique to them. As such, the extraction of the strengths and weaknesses of these two fields are still unknown. Virtual reality has had a complicated metamorphous throughout history and lacks research into how it can be combined with visualisation, specifically narrative visualisation.
The research described in this dissertation is motivated to design a set of techniques that can be applied to any generic case when creating narrative visualisations. Specifically, narrative visualisations that are part of a virtual, immersive and 3D world. This research also offers a set of techniques for developing a 3D environment to contain narrative visualisations. This research is also motivated to minimise the issues of bias raised in regards to narrative visualisations. To resolve bias, a technique for allowing viewers of narrative visualisations to see the authors message and point of view through a favourite system is offered.

Chapter 1.2 – The Narrative Visualisation Task

Gun crime across the United States and the discussion of gun control that ensues continues to divide people across the globe. Some people point to other countries with stricter gun control as proof of its success while others point just as quickly to countries with no gun laws that experience minimal gun related crime. Others debate that the United States is a unique case and as such other countries experiences cannot be used as examples. This line of discussion leads to questions of poverty, ethnic backgrounds, mental illness, and gun laws themselves as the possible causes of the violence. With so many conflicting statistics, multiple variables, and complex ecosystems the debate surrounding gun control has become an issue of big data analytics and has already seen some attention in data visualisation [4-6]. However, the debate surrounding gun control is not simply a discussion of statistics as people have vested interest and therefore emotions in the outcome. Specifically, those living within the United States are swayed by emotions whether it be fear of mass shootings, the want to be able to own a gun, or those that feel that it is their constitutional right to own a weapon and defend themselves. This unique combination of complicated statistics, divisive opinions, and emotionally charged debate creates a hostile environment for discussion and statistical analysis. The combination of data visualisations data centric approach and narrative visualisations advantage of being emotionally impactful lend perfectly to this complicated debate.

Chapter 1.3 – Research Question and Study

Complicated datasets combined with emotionally charged debate is an ideal subject to test the advantages of narrative visualisation. Enhancing data visualisations with narrative trends allows a clear and explicit message to be delivered, removing the ambiguity and concerns about bias reporting from the discussion. Furthermore, the advantages of presence found through virtual reality [7-9] can be applied to these visualisations to strengthen the connection between the user and the data. Presence is the sense of being in a real physical space despite actually being in a virtual environment and is the greatest strength that VR has to offer. VR also allows a greater spatial understanding and can allow more natural interactions.

This paper aims to answer the following questions:

Is a narrative visualisation enhanced by the inclusion of Virtual Reality technology?

What are a set of suitable techniques to develop narrative visualisations in virtual space?

To answer these questions a user study will be performed. Within the study a set of data videos [10] will be placed throughout a virtual space. The users will be asked to explore the environment and interact with each narrative visualisation. The study will be split into two groups, the first will use a standard desktop display while the second experience the study through a virtual reality headset, specifically the HTC Vive. Throughout the experiment the user will be able to 'favourite' visualisations that they feel carried relevance or were impactful. At the conclusion of the study the user will be able to compare the visualisations they favorited to the one that the author felt were the most important ones. By opening this channel of communication between the end user and the author it is believed that a clearer understanding of the authors intentions will be understood by the user. Output for this study will include information recorded throughout the study as well as a filled in questionnaire by the participant that asks them to grade the medium they used and the experience as a whole.

Chapter 1.4 – Contributions

This paper aims to make a number of contributions to the field of Virtual Reality and Data visualisation techniques as well as contribute to new techniques and ideas for the field of Narrative Visualisation. The contributions made by this paper are:

- A visualisation technique for taking statistics gathered through data analysis and create data visualisations that incorporate narrative techniques to enhance the experience. The technique focuses on creating visualisations with a motive or purpose.
- A strategy for deploying these visualisations into a 3D environment allowing exploration and interaction on the part of the user or viewer.
- Finally, a user study that tests the effectiveness of this strategy to induce a sense of presence from the user as well as create a convincing narrative.

Chapter 1.5 – Paper Structure

Within this chapter a brief introduction to the topics and an overview of the contributions and research questions have been provided. The following chapters are as follows: Chapter 2 outlines background information for the topics of this paper as well as the literature review of previous and related work to the paper. These topics include Big Data, Data and Narrative Visualisation and finally Virtual Reality. Following this, Chapter 3 will discuss the technique that this paper offers for the creation of thought provoking narrative visualisations. This chapter will also describe the design process for the virtual space and a discussion of the chosen topic. In Chapter 4 the user study will be discussed with the first section discussing how it was set up following by why it was designed in that method. Chapter 5 will discuss the results of the user study with a focus on whether or not the results reflect the research questions of this. Chapter 6 will then discuss any possible improvements that could be made to the study and discuss the opinions of some of the participants. Finally, Chapter 7 will be a final conclusion on this paper and its main contributions with some possible avenues for future research and design.

Chapter 2 – Literature Review

In this section past contributions to the fields of Virtual Reality (VR), Data Visualisation (DV) and Narrative Visualisation (NV) will be explored. Sometime will also be directed at Big Data and how it has affected the major contributions of this dissertation. As mentioned this section will be split based on the four major aspects of this dissertation with Big Data being first followed by Data Visualisation, then Narrative Visualisation and ending with Virtual Reality.

Chapter 2.1 – Big Data

This section aims to give an overview of what Big Data is and why it is currently a massive area for research. Following this, Big Data's effect on the other major research areas of this paper will be discussed. This section is comparably shorter as Big Data on its own is not a major focus of this dissertation but rather is a crucial factor as to why other areas of this research are important.

Chapter 2.1.1 – Definition

In its simplest form, Big Data simply means any large set of data. Using this definition Big Data can represent a massive array of possibilities. To filter down what Big Data really means it is best to look at not just how much data there is but what it represents, where it comes from and what can possibly be deduced from it. From this way of thinking it may be better to define big data as a massively complex data set that has a large array of possible inputs and formats that can theoretically be used to extract useful information or knowledge. Yet even with this expanded definition it still fails to encompass all of Big Data and this alone is one current problem with Big Data. One paper states that "Berkeley School of Information published a list with more than 40 definitions of the term [Big Data]" [11]. With such a massive wealth of research on just how to define Big Data this paper will instead try to tackle this issue by showing an example of how Big Data can be used.

Chapter 2.1.2 – Big Data Examples

To understand what Big Data is it is best to look at an example of how it is used in a way that most people would have had experience with. Facebook is a massive social media website where users can post statuses, comment/like other statuses, or link images/external links to other sites. With hundreds upon thousands of users the amount of data quickly becomes unwieldly. This in essence, is what current research into Big Data is about. The "Timeline" feature of Facebook, designed by Nicholas Felton [12], is one example of Data Visualization (DV), a technique being researched to view and sort this massive amount of information.

However Social Media is not the only area in which Big Data is an issue. Large data sources can be found in almost all fields; be it measuring devices, radio frequency identifiers, meteorological data, remote sensing, location data, video streaming, academia/research and search engines just to name a few [12]. In the case of search engines, petabytes of data are being stored, labelled, categorized and then searched through every second as millions of users access the system.

Chapter 2.1.3 – Big Data is a Big Problem

Now that it is clearer what Big Data is, it is important to look into why it is a problem and why it is worth researching possible techniques to help solve the issues in the field. Big Data has steadily grown in both popularity and relevance. As of 2014 a search on Google for the phrases “Big Data”, “Analytics” and “Data Science” return 822, 154 and 461 million results respectively [13]. This clearly shows that these fields are getting massive attention from researchers. But it is not just researchers that are looking into Big Data, businesses are getting on board as well with 70% of large organizations already purchasing external data which is expected to increase to 100% by 2019 [11]. So, Big Data and data science are becoming massive, multi-million dollar industries, but why is this happening and why is it a problem? To answer why it is happening its best to look at what is changed over the last 10-20 years to make this industry at first viable and now crucial to businesses of all sizes (Figure 3).

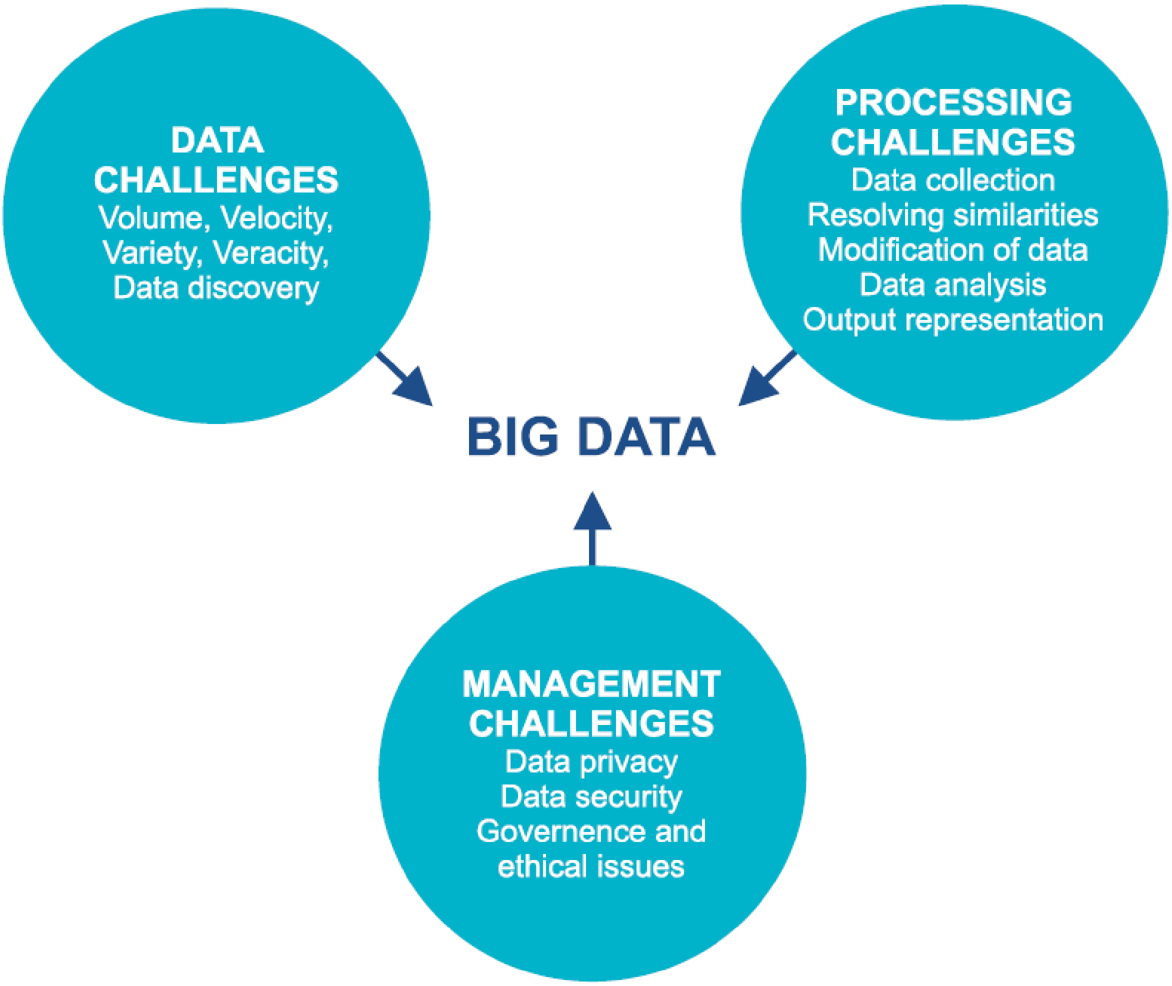

Figure 3 The challenges of Big Data. Illustration shows the major areas involved in Big Data. [11] (Image courtesy of Ekaterina Olshannikova).

The first major change over the last 10 years that has led to the increased focus on Big Data is the increase of data in the world. *"Data volumes have grown exponentially, and by 2020 the number of digital bits will be comparable to the number of stars in the universe."* [11]. Couple this with the availability of information making it easier for both businesses and individual researchers to access this information and the amount of data available to one person has become a massive gift to research, but also a massive issue [11]. On top of this data storage has been consistently getting cheaper as both Moore's law continues to hold true as technology is getting either twice as small or half as expensive and new technologies like Cloud Storage are completely changing how we store and access data [12].

Despite the advancements in technology the biggest issue with Big Data still requires further research. How can all this data be taken, converted into information and then be shown in a way that is both focused and representative of the whole dataset. The field of research that aims to solve this issue is called Data Visualisation and is a major area of research at the moment as well as one of the major factors of this paper.

Chapter 2.2 – Data Visualisation

Data Visualisation has continued to get more and more attention from researchers as well as from businesses as data has continued to grow and the need to be able to visualise this information has become increasingly crucial. As such, research has focused into what can be done in data visualisation to solve this issue and of these suggested solutions which ones are most effective. To delve into the work in this field a brief discussion of what it means to be a visualisation and how data visualisation takes on these properties will be explored. This section will include a brief history of some visualisation techniques that may be familiar to people outside of the research field as data visualisation is an area of study that is applicable to a wide array of applications. Next, a look into what current research already exists for data visualisation and what is being done to adapt this field to the new, data reliant, landscape is discussed. Finally, a survey of the new emerging field of Narrative visualisation will be discussed with focus on what it adds over conventional data visualisation methods and how it applies to this particular paper.

Chapter 2.2.1 – Definition

As was discussed with Big Data, it is crucial to fundamentally understanding what it means to be a data visualisation and what difference that makes between standard visualisations, which have existed for hundreds of years, and the data visualisations that are being created and studied today. One paper already aimed to discuss data visualisation in its modern setting and decided that the goal of visualisation is to take something that is generally unseen or indistinguishable and bring it into seeing [14]. This definition fits into the New Oxford Dictionary's definition of Visualisation, "1. Form a mental image of; imagine. 2. Make (something) visible to the eye". Both of these definitions revolve around the concept of taking something, be it unclear, hidden, fictitious or ambiguous, and reveal it to the common eye. While this definition does lead to some unusual, if not totally accurate, conclusions (by this definition reading glasses are a form of visualisation), it does paint a background for how visualisation has changed over the years. Basic visualisations would include most visual art works, ranging from cave paintings to modern film and other media that allow the author or authors to express a feeling or convey a message that would otherwise be difficult to see or understand.

Chapter 2.2.2 – Visualisation without Data

One thing that may be obvious when discussing the definition of Visualisation is that there is no mention of Big Data or technology. This is because although data visualisation is a crucial part of this research it is important to look into what visualisation is capable of regardless of whether it is being used to represent and visualises data. In this section, a few examples of visualisation that have garnered success or positive results will be discussed.

Research into investigating how visualisations and its methods can be applied to the problems of Big Data have found a few interesting examples of visualisation techniques that think outside the normal, visually focused, method of describing an otherwise intangible concept. In “Abstract to Actual” by M. Hohl [14] there was a visualisation described in which the abstract concept of a “Watt”, a measurement used to describe energy consumption of a device, was described via the user undergoing a specific experience. The experience used was that the participant would climb onto a simple home-trainer bicycle and was asked to pedal. This act would then generate watts which was shown to the participant on a screen in front of them. While doing this, if the participant reaches a certain threshold of watts the system would notify you as to what exactly your current level of Watts generated could do, for example it might say “You could light a 20 Watt light bulb now”. The context in which this visualisation was used was to help the user understand exactly what is required to power a simple two-bedroom home. There are many different avenues to take in describing this issue but by getting the user physically involved it used the participants own personal experience to give weight to a point that would have otherwise been a number on a screen without context. Obviously, this specific technique is limited and cannot be applied to any visualisation problem, take for example the context of this dissertation in which the dangers of guns in the United States of America are the talking point it; is difficult to get the user’s own experiences to aid the visualisation unless perhaps the participant has already had an incident in the past.

Another example from the same research showed a visualisation technique for describing how the oceans tides work. The tides, if explained through physics or mathematics, is an extremely confusing and complicated system in which the planets and their gravitational forces actually pull the water from the earth and cause the tides that we see in the ocean. However, to help explain this complicated system, a series of rotating glass spheres which represented the Earth, Moon and Sun were used. With each of these orbs there is also a friction device that can cause each orb to vibrate in such a way as to create a noise of different pitch and volume. The orbs also have water inside them which replicates how the water would be behaving on that planet. With the combination of this, varying music, and the visual component of actually seeing the water change the user can see exactly how each orb affects the other orbs and with only a few simple concepts can help visualise an extremely complex process. Just like the example before this process has limitations. While the tides are a complex concept to describe there are other complex ideas that are harder to visually and physically represent. It does however give a good example of converting information from one format to another. By using friction devices this visualisation was able to convert the influence of gravity, and experience that is almost impossible to replicate, into a sound that can be heard and audibly distinguished as it changed.

These examples highlight that the area of visualisation is ripe with opportunities to find clever ways to help describe concepts and problems that otherwise would be difficult to distinguish. It should also be considered that the power of a visualisation to explain a problem does not only help the participant but can also be a powerful tool in helping the author discover and understand concepts, and in the case of large data sets, patterns that otherwise would have been missed. M. Hohl concluded his research findings by saying that those that wish to create memorable and effective visualisations "must look into new and evocative manners of presentation and visualisation and combine this intellect and embodied experience to address multiple sensorial modalities such as sound and touch".

Chapter 2.2.3 – Implementations of Data Visualisations

In this section the focus is on how modern visualisations are being used to find information that would otherwise be impossible to see and represent it in a way that allows other people, who may or may not be familiar with the underlying data, to not only understand the information but hopefully use that information to make informed decisions.

Data visualisation is a subset of all visualisations. They are focused on describing data sets, of variable size and complexity, for a variety of different results. There are three major stages for data visualisation, the first is the collection of the data. This is the raw information for which all subsequent visualisations will be created from, this dissertation is not focused on this section. The second stage is where visualisations may first be created. This is where the data analyst or computer scientist that is working on the data may compile the results into a visualisation that helps plot the information in a way that make sense and is human readable, examples of these visualisations include standard mathematical visualisations like bar charts. Some more advanced versions of these visualisations include experimental research into using Virtual Reality [15, 16] and simple forms of interaction to help filter and group potentially relevant information. Visualisations at this level are a key area of research as it is difficult to extract meaning from a massive dataset without some level of control of the data. However, it is in the third and final stage of data visualisation that this project belongs. The final stage assumes that useful patterns or observations were extracted from the data visualisations in the second stage and now the author wants to represent the results in a way that is not only human readable but is able to tell a story to the end user. Unlike the first two stages of data visualisation where the end goal is generally consistent regardless of the information being used, that is to represent the data in a clear and useful manner while maintaining an objective viewpoint, the final stage could be used to frame the information in a deliberate way. This difference raises possible issues of objectivity for this particular category of visualisation, and whether a visualisation whose author has deliberately aimed to frame the information in a certain way can be relied upon. This final stage is where the work in this paper fits in as it does not use the raw data but instead focuses on taking the statistics found from this data and displaying it in such a way as to reinforce an opinion or viewpoint. However, it is important to understand what data visualisations at the second level look like and how they encompass a majority of current visualisations.

When discussing data visualisations, it is important to understand that data visualisations encompass a massive area of visualisations. And attempts to visualise or represent data of any kind can possibly be included in this definition. For example, one of the lowest levels of data visualisation that may be recognisable is that of charts and graphs. A simple chart whether it be a bar chart, line chart or pie chart [17] are all forms of simple data visualisations as they help describe a dataset and can be used to extract relationships between data as well as patterns and trends. These examples are on the lower end of the data visualisation spectrum due to the relative simplicity of these models. Despite their simplicity these simple visualisations have been proven to be so useful that they are now staples of both the mathematical and scientific fields. These examples are also inapplicable to solving big data related issues, due to their inability to work effectively for much larger data sets or for datasets in which the structure is unformatted or only weakly formatted. This is a major drawback for these standard mathematical visualisation techniques as being applicable to large datasets has become a crucial quality for data visualisation techniques. To tackle this new problem a survey of a few more modern attempts at data visualisation should be explored.

C. Chapmans' "*50 Great Examples of Data Visualisations"* [18], a website that collected a whole list of interesting and effective data visualisations, is a great place to start looking. C. Chapmans webpage is a collage of fifty different data visualisations that employ a wide array of techniques to display a wide range of possible data sets from the different audio channels of a music track [19] to mapping out a user's bookmarks [20] all the way to visualisation the scientific advancements of ten different nations [21]. While each of these visualisations bring something interesting to the field and blends current techniques with new and innovative ideas to advance the field of data visualisation it would take a hundred pages just to go through all of them. So in the interest of time only a few visualisations picked out for their interesting design, thoughtful implementation or relevance to this dissertation will be discussed.

The first visualisation is interesting not because of its techniques, or for having a particularly well designed or thought out method of presentation but for what data it chooses to present. The data visualisation named "Is the New" [22] is a visualisation that maps uses of the phrase "is the new" i.e. "30 is the new 20" when discussing ages, and tracks what subjects and objects are being used with that phrase (Figure 4). While it is unclear exactly what sources this visualisation receives its data from it is an intriguing concept. It allows the reader to see how people's discussions have changed and what topics are being compared to other topics.

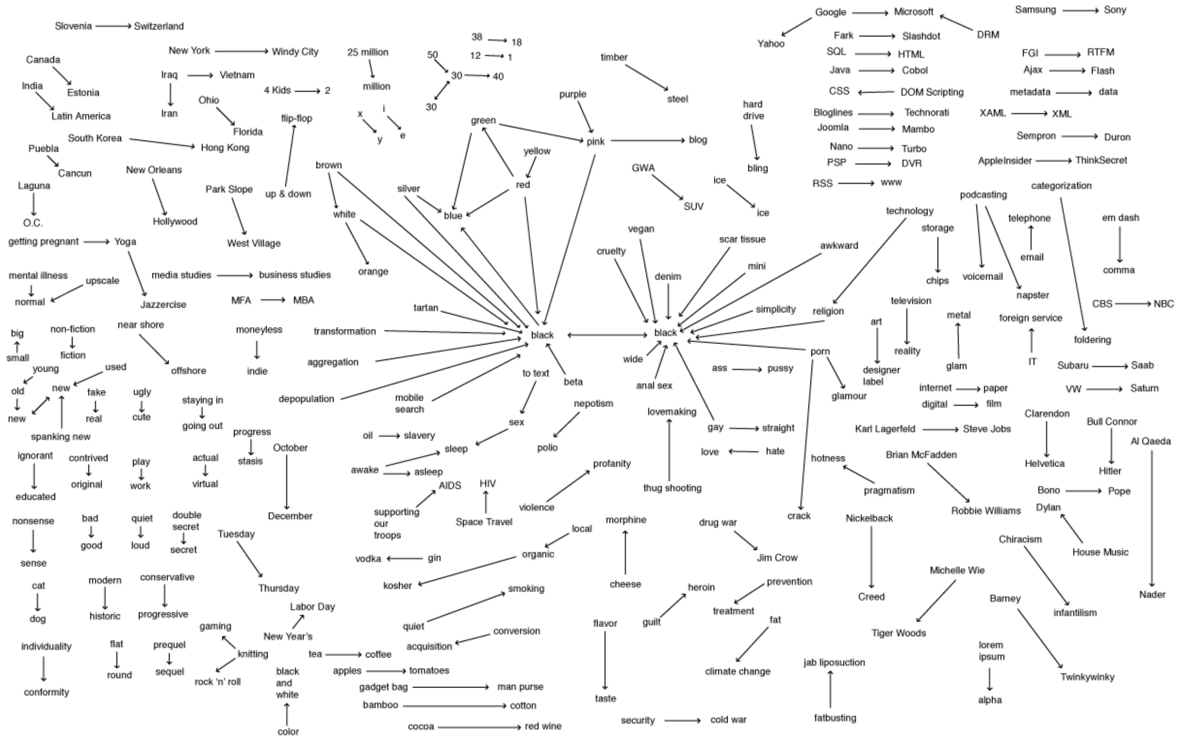

Figure 4 "Is The New" visualisation [22]
(Image courtesy of LeisureArts)

From a visualisation that was unique for its data and less for its visualisation to a visualisation that tracks quite mundane data but displays it in an interesting way is "1 hr in front of the TV" [23] (Figure 5). This visualisation tracks the movements of four people through a living room for one hour. At first glance this might seem an unusual topic for a data visualisation but it allows a representation of a story, of a series of events through data. The visualisation works through the author using a marked-out grid which was created using masking tape to plot the movements of a father, his son, his daughter and their cat across the room. The creator then took this video and plotted it to a room map of the living room. Different colours were used to separate the different users and a minimalist style background was used to help highlight the important information. This visualisation almost passes beyond simple data visualisation and becomes a narrative visualisation. Telling the story of these four people over the course of an hour. One example narrative is of the cat's movements; the cat can be seen to move from a heat source on the left of the room, over to a heat source on the right side of the room before deciding to leave the room. While not a thrilling story it is told completely through objective data with human insight. It might be hard at this level to understand what useful information could be retrieved from this visualisation, and in its current state that may be nothing. However, it could be grown to include a greater period of time, more rooms or even different houses and from that perhaps more conclusions could be drawn.

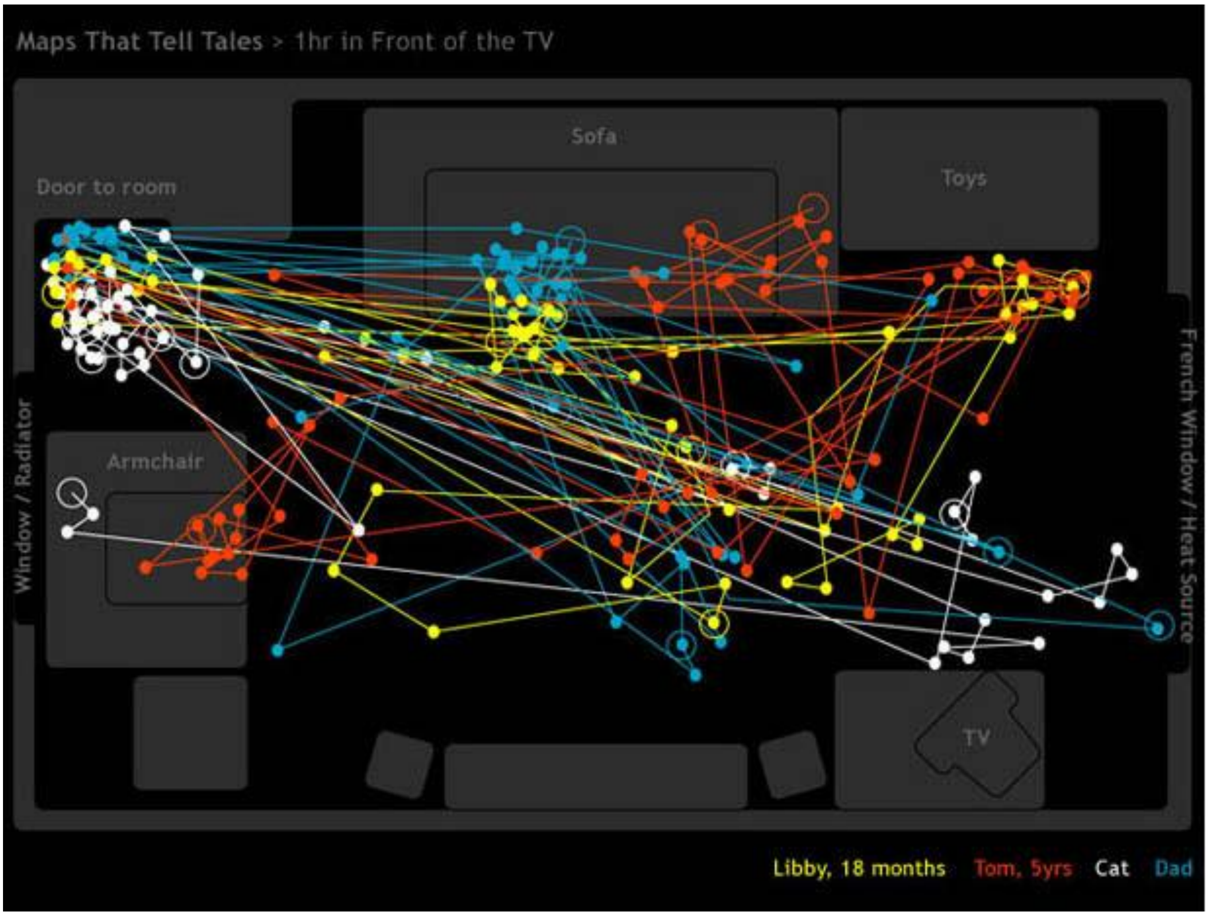

Figure 5 "1hr in Front of the TV" visualisation, colour coded legend (bottom right) [23]
(Image courtesy of Bumblebee)

This next visualisation is the first to highlight what advantage more modern approaches to data visualisation can accomplish when it comes to representing large amounts of data. The visualisation, named “We Feel Fine”[24] (Figure 6), aims to take social media and “blogosphere” information and use it to show how different people, of different types, are saying they feel like at this moment. This visualisation follows a popular trend of a lot of modern data science by focusing on data mining information from social media which is one of the greatest sources of information openly available to people. In this case, messages or statuses in which the term “I feel” is used is taken, the data about the person sending it is recorded and the general emotion that the user claims to be feeling is catalogued. The emotions are catalogued via different colour splotches of paint or sometimes as the actual text itself. To represent this data, “We Feel Fine” has a set of methods for filtering and viewing the information. Some of the filters include the age, gender, location, emotion, date and even weather. The filtering options are very flexible and allow minute control over what information is viewed. The art style for this particular visualisation is also concise with stark contrast between the black background and the vivid and bright colours for the emotions or data. As well as all these options at any point the user can choose to click on a certain splotch on the map and see the message that created it, this is a clever method for allowing the user to understand not just what this visualisation is showing but how it got there.

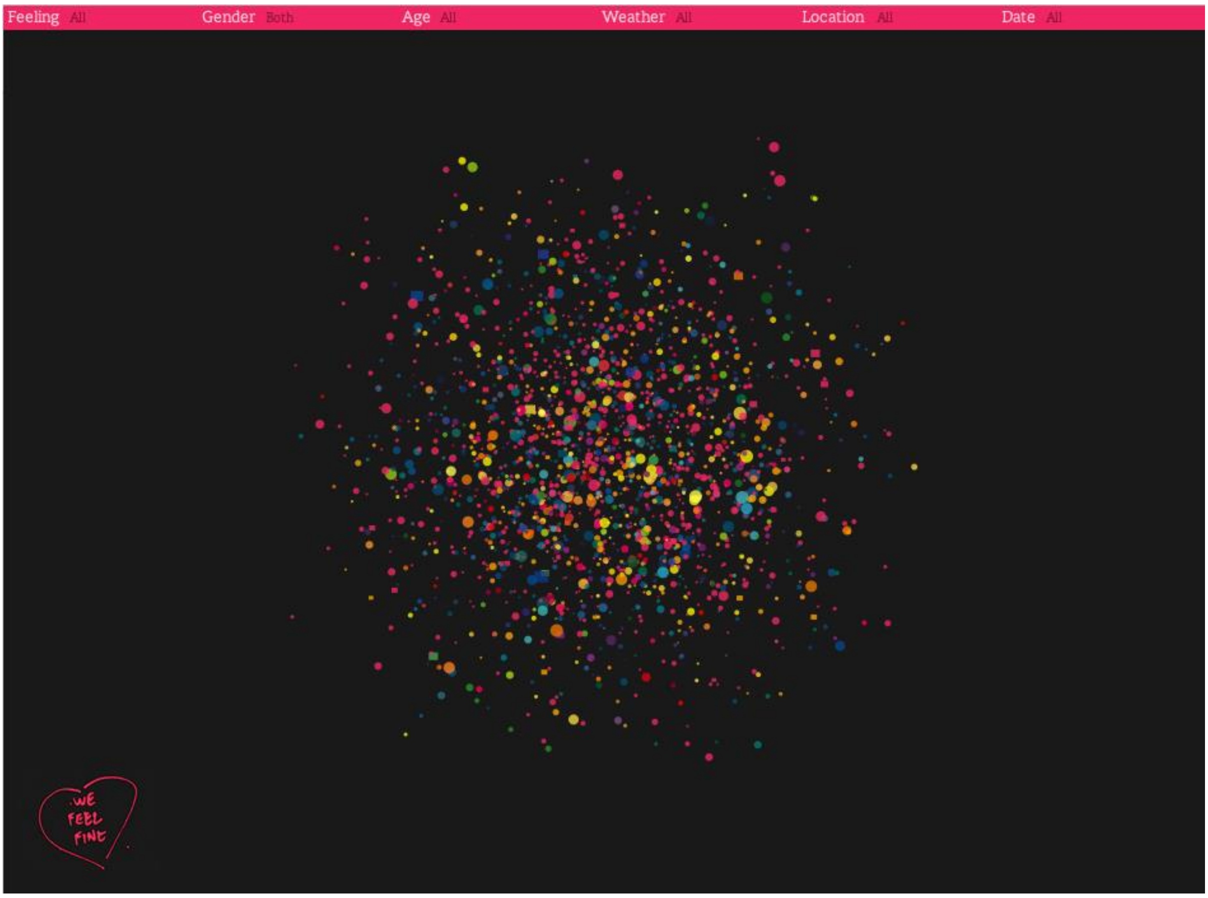

Figure 6 "We Feel Fine" visualisation. Each particle represents a different persons emotion. [24] (Image courtesy of Sep Kamvar)

The visualisation “One Week of the Guardian” [25] uses a number of different visualisations and techniques to describe and present the information released by The Guardian newspaper over the course of one week. The visualisation uses a different visualisation for each day which highlight different information in different ways for each case. In the interest of time only a few of the most interesting choices for the week will be discussed. Starting with Monday, the first visualisation takes information about each section including word count and number of articles and represented in a bar chart. To enhance the visualisation, it uses the metaphor of a nutritional information label to help break down the numbers and describe the information. This is the first example of metaphors being used in visualisations to aid the reader. Metaphors are a powerful tool in many fields for helping describe the functionality or significance of a piece of information. In user interfaces a good example of a metaphor is the recycle bin on PC computers being used for trash. The relationship between a bin and rubbish is implied and reduces the difficulty for a new computer user to understand the functionality. The second day, Tuesday, is a simpler concept. It takes the headlines of the different articles and highlights or modifies certain words to increase focus or to help connect the stories. For example, any mention of a country is wrapped in a flag from that nation. The third visualisation is a way to describe how one day's paper is divided up content wise. Using colourful concentric circles to describe the different categories of news, the circles closer to the centre take up less of the paper whereas the last circle is the subject of the majority of the paper. It also has page number and word counts pinned to the circle to see where the individual stories are for each category. This visualisation is particularly interesting due to its vibrant look and how it effectively gives the viewer a snapshot of what the paper is about. The final visualisation that is worth discussing is for Thursday (Figure 7). This visualisation is a network graph that aims to connect four different properties for each article. The categories include headlines, authors, page numbers and categories. Lines are drawn from each of these properties to represent a single articles information. Simply following one coloured line will tell the reader what the article is about, what the headline is, what page it is on and who wrote it. The most interesting question that this visualisation leave un-answered is how to make it more readable. With so many lines drawn within the circle it can be difficult to find any one piece of information. This issue raises questions about possible methods of interaction and filtering that could exist to alleviate this issue.

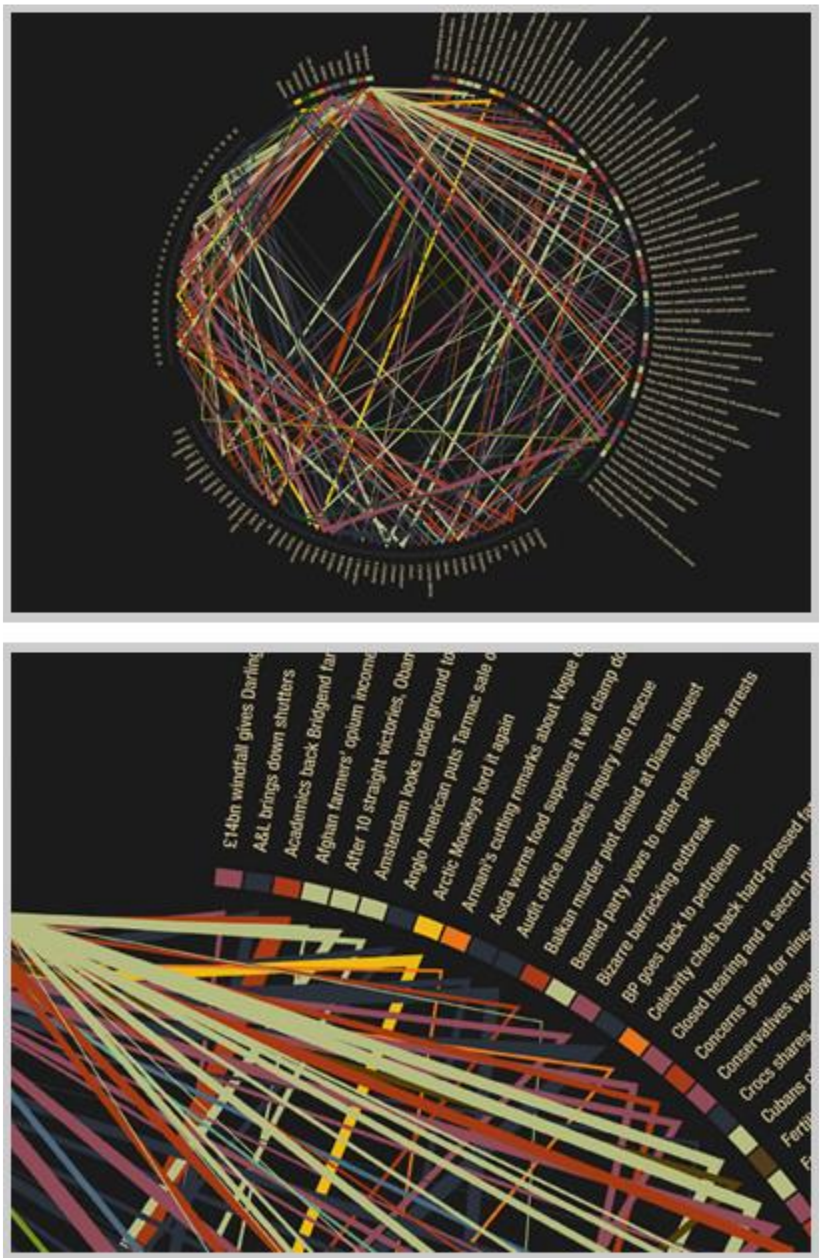

Figure 7 "One Week of Guardian" visualisation. Thursday visualisation showing headlines, authors, page numbers and categories. [25] (Images courtesy of Dave Bowker)

One thing that none of these visualisations managed to show is how these visualisation techniques can be used for more than just creating visually pleasing images. The major advantage of a data visualisation is its ability to highlight important information and one example of a visualisation that was able to achieve this was “Forensic triage of email network narratives through visualisation” [26]. In an attempt to use data visualisation techniques for real world applications this paper took on the case study of the Enron Fraud. In this case study the Enron

Company, a large energy company, was found to be guilty of fraud. Particular focus was given to the CEO Jeffrey Skilling, whose emails contained information crucial to revealing the fraud. The study aimed to show that data gathering techniques combined with data visualisation would help to reveal this information avoiding the need to sift through each email individually. For gathering the data from the email corpus an automatic tool named TagSNet (Tag cloud and Social Networks) was used. This system was able to gather both qualitative data, data that refers to the actual content of the emails, and quantitative data which refers to the information in the network. This includes who sent the email and who received it and other such Meta data. Once the information had been collected it was then required to decide how to visualise this information. Two visualisations were eventually used to represent both the qualitative and quantitative information. Two represent the quantitative data a web like structure was used with the CEOs email address as the centre and all the other email address that emails were sent to being connected to that centre point. Depending on how many emails were sent to these other addresses affected how large the representation for that address would be. This visualisation allows the analyst to immediately see what other email address could be relevant to this investigation and which ones are most likely not important. The second visualisation was used to represent the qualitative information of the emails. To do this a visualisation would be created for certain addresses or sections of emails. Using the content of these emails a tag cloud was created in which all the most commonly used words within these emails would be bunched together like a cloud (Figure 8). The more often a word was used the larger it would appear in the visualisation. This visualisation was useful in disregarding or prioritising certain corpuses of emails as word that were considered irrelevant/relevant to the investigation could be seen in these tag clouds. This case study eventually showed that not only were these techniques faster than manually looking through the emails but that they also resulted in relatively accurate results. This study is just one example of how data visualisations can be used to achieve a real outcome and cause conclusions to be reached from a data source.

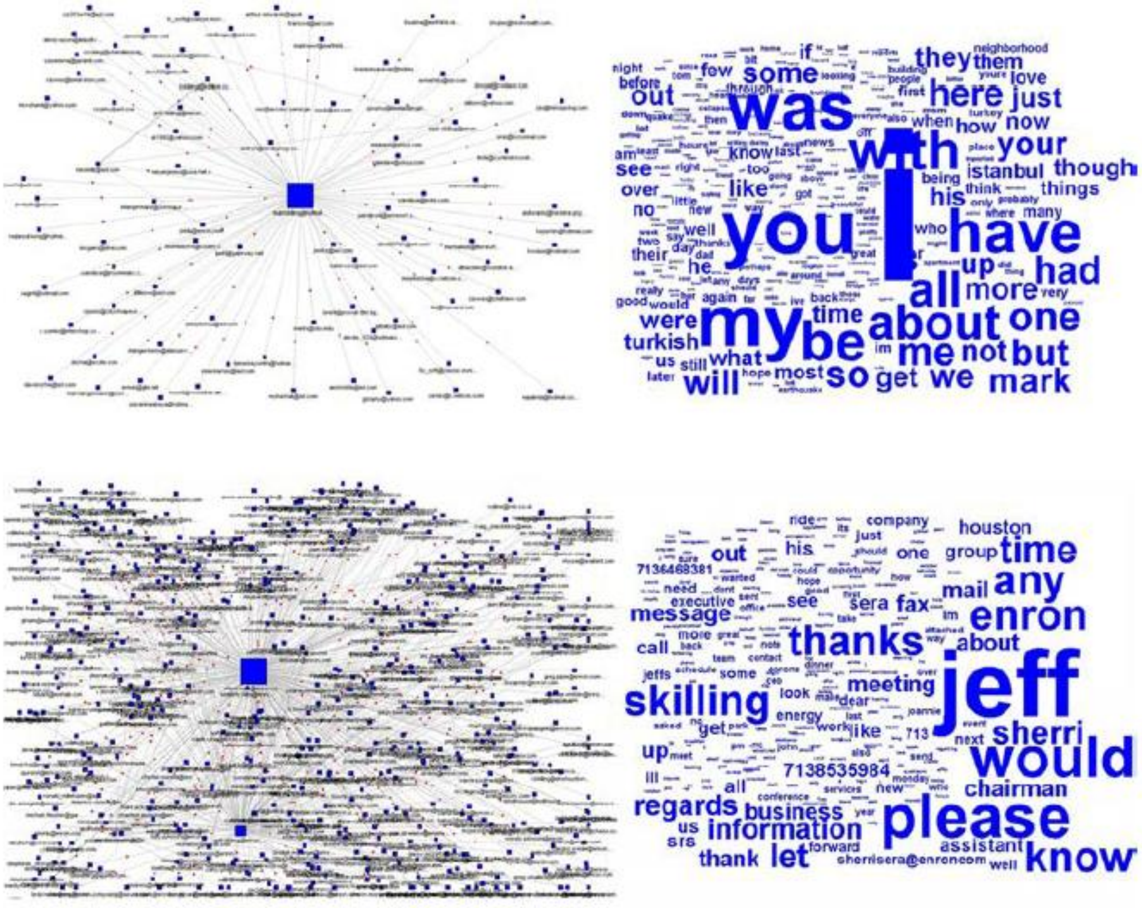

Figure 8 Forensic Triage visualisation showing the network narrative for two separate email folders. [26] (Image courtesy of John Hafferty et al.)

Chapter 2.2.4 – Analysis of Data Visualisations

These different visualisations show how varied both the methods for representing data can be as well as the information itself. This is not even close to an exhaustive list and the data varies from tracking the movements of people to word counts and subjects in newspaper articles and the methods range from bar charts to colourful illustrations representing how the world currently “feels”. With this information, it raises a question of what makes a data visualisation successful and what rules or patterns can be observed in popular visualisations. To answer this some research has been done into the structure and interaction within data visualisations. Some of these articles will now be discussed.

To start “A review of overview + detail, zooming and focus + context interfaces” [27] looked into what display techniques already exist in the field at the moment. Most of these fields are not necessarily unique to data visualisation as they are used in many different forms of visualisation. They found that there were four main categories in which a visualisations structure and navigation could be categorised.

- The first technique is labelled as **Overview + Detail**: In this structure there are generally two separate views being shown to the user at the same time. One is generally showing the entire dataset while the second section of display shows the currently highlighted section or detail view. While there are multiple ways this separation of views can be done, a common example is through a scrollbar. Microsoft’s PowerPoint is an example of this structure. With the left side scrollbar showing all the slides and the right section showing the currently selected slide.
- The next technique is defined as **Zooming**: In this structure the user has the control over the viewpoint and via some method of interaction the user changes the level of the dataset that is visible. Within this category there are two separate implementations with a fixed level of zooms in which the user changes between a set amount of levels or a free level of scroll in which the user has analogue control of what they see. The biggest drawback of this technique is that lack of spatial understanding the user has compared to **Overview + Detail** due to not having a clear picture of the entire scene has they zoom.
- There is also **Focus + Context**: This structure aims to take the major advantage of **Overview + Detail** and add the power of focus that is achieved through **Zooming**. The way that works is by giving the user a clear understanding of the overarching structure while being focused, through some graphical trick, on a specific portion of the dataset. The most common and popular example of this in the visualisation community would be the fisheye view. In which there is a blurring effect around the main focus which is magnified. Another example could be the Mac OSX taskbar where the icon selected by the user is maximised while the icons immediately to the left and right are shrunk. A quite different example of this structure would be in some Integrated Development Environments (IDE’s) in which sections of code can be collapsed or shrunk to allow for more readability. The issue that this structure has that the two mentioned above do not is in the manipulation of the dataset. To create the enhancing effect on the current

information the information around it is edited to look less interesting. This could lead to false assumptions or incorrect data readings if not applied properly.

- The final technique is **Cues**: These cues change how objects and data is rendered within the visualisation to help represent focus or importance. One way this could be implemented is by using a z-index based visualisation in which information that is important is at the front and less important information in the background is blurred to reduce attention.

This is not the only paper to discuss different structures and how they can handle navigation, E.Segel and J.Heer “Narrative Visualisation: Telling Stories with Data” [3] paper not only introduced the world to the phrase “Narrative Visualisation” and created an entire subgenre of research and design but also discussed how these visualisations can be structured. While this paper discusses narrative visualisation in particular, this information is still relevant and both narrative and data visualisations share a vast majority of properties.

To start the paper suggested three possible considerations to handle when designing a visual narrative. The first is considering the visual structure. This does not necessarily include the actual structure itself, which is obviously important, but actually focuses more on communicating the structure to the user as to aid them in understanding navigation as well as being able to inform the user of their current position within the visualisation. The next consideration is with highlighting; these are the visual mechanism that are used to both grab the users’ attention towards certain information or important concepts but can also be used to represent what the user is currently selecting or focusing on. Some example properties that can be changed for highlighting include size, audio cues, motion, framing, colour and flicker [28]. Finally, the third consideration is transition. This involves all navigation between the different parts of the visualisation. Some things to consider when deciding on transitions is how to not disorientate the user to avoid them losing a sense of where they are. Some simple methods for this include animated transitions, camera movement or object continuity (where everything moves around a focal object in some way). They concluded this discussion by creating a spectrum of approaches into how these visualisations operate. The spectrum varies between an “author-driven” approach and a “reader-driven” approach. The properties of an author-driven approach were one that limited interactivity. At the other end of the spectrum is the reader-driven approach which replaces a strict structure with a high level of interaction where the user makes all the decisions. To describe this spectrum through current storytelling devices a standard novel would be an example of author-driven, where the writer has already set out everything that will happen and allows only one ordering of events for the reader to explore. On the reader-driven approach a video game in which the character has free roam of the world and events are only activated by the user. In the middle could be a more story driven video game in which the user is given a list of choices available to them or a “choose your own adventure book” where the user has some control over what happens to the characters and narrative but is limited to choices allowed by the author.

E.Segel and J.Heer also mention a few different structures these visualisations can use that all fit somewhere on the author/reader driven spectrum. The first one mentioned is the “Martini Glass Structure” which is where the visualisation begins with a linear structure that shows one visualisation after another with minimal interaction or navigation set upon the user. It then expands out to allow the user free choice and the ability to move around the different visualisations or views with minimal limitations. Second is the Interactive Slideshow structure. This structure is similar to the slideshows structure most people would be familiar with. The major departure from the general structure is an increased focus of interaction within each slide. The third and final example structure discussed was the Drill Down Story. In this structure the user starts the visualisation with a road map or global view of the entire system. From this point the user can choose to go deeper into a certain logical subset of information or visualisation. While doing this the user can only go deeper down or recede back up towards the global view.

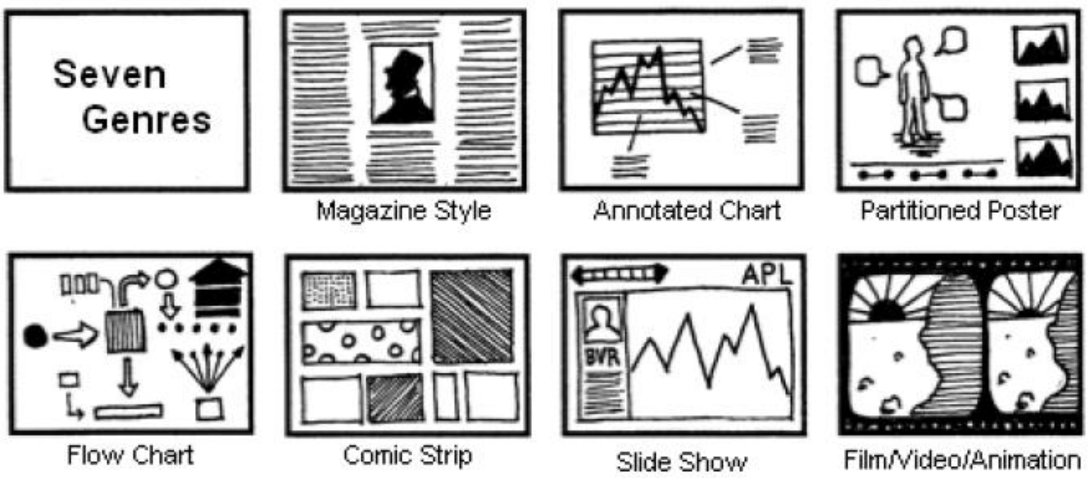

Figure 9 Narrative visualisation genres defined by E. Segel and J. Heer. [3] (Image courtesy of Edward Segel and Jeffrey Heer).

These categories highlight a certain possible set of structures for any kind of visualisation but are not a complete list. Something that all these structure hint at but never go into detail about is how the user can then interact with the information. For example, in the Zooming example it is never specified how exactly this zooming should be done. There is no exact one right way of interaction but it has led many to research into what methods of interaction exist and of these methods, which are the most effective. Within this paper they also discussed a set of genres that they noticed for narrative visualisations (Figure 9). A study [29] that aimed to use a "Node" structure to organise its visualisation claimed that there are two major components in any modern information visualisation. The first was the representation techniques used. These techniques need to be focused on how the datasets can be mapped to computer graphics or rendered to a screen. The second major component was interaction. This component is focused on how the user can communicate with the data and how the data can be explored and in some cases manipulated to allow the user to uncover interesting patterns or insights.

J.S. Yi [30] proposed a structure for visual interaction models that are and can be used within a visualisation. These layers were labelled as:

1. Select: Marking a particular object or section of data.
2. Explore: Look at a different section of data than the currently selected.
3. Reconfigure: In some way restructure the current information to look differently.
4. Encode: Similar to reconfigure but with the emphasis being on the visualisation being shifted to represent the same data a different way.
5. Abstract/Elaborate: Increase of decrease the amount of information available.
6. Filter: Show me a subset of data based on a condition.
7. Connect: Show other information related to the selected data.

These seven layers are ordered from lowest levels of complexity to the most complex layers. This structure is a few years old but still manages to encapsulate most if not all of the current methods of interaction seen in data and narrative visualisation. The methods to achieve these interacts vary from standard desktop peripherals like keyboard and mouse to more complex hand held interaction tools used in some VR settings or even complicated hand tracking software that uses no other devices other than the users hand and figure gestures. It is worth noting that most if not all of the layers to visualisation described here are not exclusive to data visualisation but in fact can be mapped to almost all interfaces used today. This is because visualisation, just like all new mediums before it, is designed based off of previous experience and expertise. It is due to this way of thinking that a lot of the observations made in this section can apply to sub-genre of data visualisation known as Narrative Visualisation.

Chapter 2.2.5 – Narrative Visualisation

E. Segel and J. Heer first coined the term "Narrative Visualisation" in their paper "Telling Stories with Data" [3]. In this paper, they discussed an emerging trend of online journalists incorporating data visualisations into their articles to help tell stories. The article then goes on to define this subgenre of visualisation that they called Narrative Visualisation and discussed different types of visualisations that existed in this new category. These qualities and structures have been discussed in the previous structure but the design differences and unique qualities that divide data visualisations and narrative visualisation have not yet been categorised in this dissertation. Due to the fact that this paper created the entire field of Narrative Visualisation this section will focus heavily on what that paper was about and what findings it had before delving into what research has been done since to build on the design definitions set and answer some of the questions raised by it.

The paper begins with The Oxford English Dictionary definition of narrative as "an account of a series of events, facts, etc., given in order and with the establishing of connections between them". This definition already gives some insights into how the incorporation of narrative into a visualisation has effects on how they are designed. This definition suggests a connection between each stage and the one immediately following it. Where a data visualisation might use this connection as a shift of one variable say time, a narrative visualisation could suggest a correlation between information and events simply by having one following the other. As well as discussing narratives the paper discusses the connection between current data visualisations and storytelling with a quote from Jonathan Harris who authored the "We Feel Fine" visualisation [24] discussed earlier in the paper "*I think people have begun to forget how powerful human stories are, exchanging their sense of empathy for a fetishistic fascination with data, networks, patterns and total information… Really, the data is just part of the story. The human stuff is the main stuff, and the data should enrich it.*" This quote helps to highlight why narrative visualisation is crucial to solving the issues with visualisation and big data. Implementing the data into stories puts the focus on the "human stuff" that Jonathan Harris was discussing and allows the factual, raw data to enhance the story and give it credibility. The next section takes five case studies of narratively focused visualisations, primarily found through online journalism and extracted from them properties and themes that were common or interesting, most of these observations were discussed within data visualisations and structure previously. A major issue that the article discovers in that while the basic idea of incorporating narrative elements into visualisations has gained popularity and examples of it can be found it is still difficult to define what it means to be a narrative visualisation. In particular research still needs to be done into discovering the details of how best to incorporate these visualisations with storytelling.

While "Telling Stories with Data" created an entirely new field of study for the world of visualisation it freely admits to only being the start of what needs to be done before the field can be clearly defined and properly understood. A few points of future research include a discussion on the possible risks of bias that arise from injecting storytelling techniques into data visualisations, discovering what is encapsulated by storytelling and narrative and how best to define them and finally into what strengths this field entails and how best to leverage those strengths when deciding how to create narrative visualisations.

Visualisation Rhetoric [31] is one paper that aimed to discuss bias and the disparity between standard visualisations and visualisations with an intended end goal of persuasion. Their discussion into this complex issue raised a few interesting points. To start past visualisation techniques, in which objectivity and a lack of ambiguity were not just preferred but the inherent default of any visualisation, were called into question for already containing possible subjectivity and bias without any malevolent intent by the author. The papers focus is on what rhetoric's the designer uses, with rhetoric referring to "the set of processes intended meanings represented in the visualisation via a designer's choices". The rhetoric choices by the author can be small, for example changing the phrasing of a fact or by drawing focus to and from certain pieces of information. In total this paper states that there are four stages in which an author can potentially, either by choice or unintentionally, add bias to a visualisation. At the data stage, visual representation stage, textual annotations and the interactivity.

1. During this first stage the author chooses what data and variables to include and what to omit. Already the author is making decisions that lead to the reduction of data, however this step is critical to any data visualisation.
2. When deciding how to visualisation the dataset even more information can be omitted or ignored as choices arise as to how best show the information. More information can be

lost at this stage as the transfer from information to visual representation is limited by the capabilities of the human perception.

3. Text annotations, which is text that is printed somewhere on the visualisation, helps to direct focus and emphasis towards a certain piece of information. Yet again, the act of focusing towards one piece of data or a certain subset can affect a user's interpretation of the information which opens up room for bias.
4. Interaction, in particular any level of navigation control, can force a user down a certain path both physically and mentally. Menu driven systems can also lock the user out from viewing certain information.

These issues apply to visualisation of any kind and show that while newer visualisations that inherently of the raw data, this risk is relevant in current visualisation that are generally deemed to be "absolutely unambiguous, with its intended interpretation being transparent" [31] and as such do not discredit these new techniques.

As well as discussing the issues with bias in narrative visualisations some research has been done in attempting to further define the term itself. E. Segel and J. Heer agreed in their paper [3] that there remains ambiguity in the definitions and restrictions of the field. Examples of this lack of definition include being able to define what a story is, what encompasses storytelling, what a data visualisation is narrative visualisations). In an attempt to refine the definition of narrative visualisation B. Lee et al. begin with J. Heer and E. Segel definition as well as J. Hullman and N. Diakopoulos' altered definition of narrative visualisation as "a genre that combines interaction techniques for exploratory control over insights gained and communicative, rhetorical, and persuasive techniques for conveying an intended story" [31]. This definition still fails to encapsulate what it means to extract a story from data and represent that story as a visualisation but does manage to include all the components that are necessary to be able to construct a narrative visualisation. Finally, the authors submit their own definition as a visualisation with the following features:

- A visualisation that includes facts backed up by data.
- Most or all of the story pieces are visualised to support one or more messages. The visualisation should also include annotations or narration to highlight/emphasise the message and avoid ambiguity.

- Pieces are connected in a meaningful order or with a connection between them to support the high level goal. Where it be to educate or entertain or persuade them with thought provoking opinions.

The strength of this definition is its strict requirement for facts and data to be the backup of the visualisation. This means that all other standard forms of story that have existed do not count as a visually shared story. for a meaningful connection or order to the sections of the visualisation. The biggest concern with this definition is that it removes visualisations that allow free exploration which in this dissertation' consideration still remains a possible component of a narrative visualisation.

Other research into narrative visualisation has focused on looking at how the sequence of information in a narrative visualisation effects the final product [32] while another paper discussed the possible advantages to the author or data analyst through constructing a narrative visualisation [33]. In this paper, Paula Jacobs et al. look at the early stages of data analysis and how framing the information in a way as to create narrative visualisations can actually aid in finding patterns or useful stories. The paper argues that while attempting to analyse the data and find effective methods of displaying the data it is easier to see them as narratives instead of statistics and extract and relate the data based off of these stories. As this is the reason narrative visualisations are popular for the user or reader it follows that these same strengths can be applied to the author as all humans have these tendencies. On top of this events found in the data could then be used to hypothesise what other results in the data may tell. The same way seeing the beginning of a story allows the viewer to make guesses on what may unfold later down the story. The authors of this paper do warn that this technique should be used with caution as to avoid speculation and be sure to verify early results especially if this technique is to be used. The paper also discusses the importance of data coherence and cohesion. They explain cohesion as the concept that each event in the story should have overlapping narrative elements and that the order of the story makes sense. If gaps in the story are found once constructed into a narrative, it could suggest a gap in the results or a missed connection. This philosophy of cohesion fits well with whole package that the narrative makes sense. This is a crucial element for narrative visualisations that aim to prove a point or convince the audience. If the visualisation lacks coherence it may be difficult for the audience to understand what the message of the story was.

The final paper to be discussed that relates to narrative visualisations is a discussion on data videos [10]. A data video could be described as a short video which takes data that has been collected and analysed and visualises it in an interesting way. They generally include a point or message and contain little to no input from the user. It is that last property which separates a data or narrative visualisation from a data video. A lack of interaction is also what makes data videos an unusual sub-genre of the visualisation field as research has shown that interaction is one of the key qualities that helps a user to engage with the data [34]. Fereshteh Amini et al. decided to investigate the current trends, methods and structures that were being used by popular data videos. To accomplish this 50 professional data videos were surveyed to find out common structures, attention cues and durations. The results of this survey found that the three most popular forms of visualisation were bar graphs, pictographs and maps, with the most popular forms of attention cueing being animation, gradual text and highlighting. An interesting observation from the study found that 48% of the total runtime of data videos was spent on visualisation and 72% if the videos focused on 5 different types of data visualisation. These results are interesting as they continue to reinforce the fact that data videos and narrative visualisations employ many if not all of the same techniques that data visualisations use. With particular note to the very same attention cue techniques that most data visualisation incorporate as well. As well as sharing common techniques it was observed that the data videos often followed Cohn's theory of Visual Narrative Structure [35] which included the following four stages:

- Establisher: "Provides referential information without engaging them in the actions or events of a narrative"
- Initial: "Set the action or event in motion"
- Peak: "The most important things happen; the culmination of an event or the confluence of numerous events"
- Release: "The aftermath of the peak"

It was found that the most common structure for the data videos involved multiple establishers with several initial elements which in general led to one peak with multiple releases following it. When considering this structure, the logic follows with the intended goal of a narrative visualisation as the peak would of most likely coincided with the summary of the point or goal of the visualisation. As well as the survey this paper also conducted a study in which thirteen experienced storytellers created storyboards for a data video given a data set. Despite the storyboards varying in details it was found that there were four distinct categories that emerged from the study.

- Factual: These storyboards simple showed the trends over time with the facts.
- Tension Builders: These structures built tension by withholding some information or showing it change through different stages.
- Viewpoint: Uses the visualization to prove a one sentence proof or belief.
- Inciting Reflection: Asks the user to consider the information at the end and shows an unusual belief or thought.

A final commend trend found in these storyboards was a constant attempt to personify the stories and data. Often using symbolism or recurrent human figures to give the information a personal more relatable feel.

Chapter 2.2.6 – Summary

Both data visualisation and narrative visualisation are large fields attempting to combat some of the issues the increasing reliance and use of big data is creating. Research has been conducted in both of these fields in attempts to discover strengths and weaknesses as well as attempt to define simple guidelines and features. Despite this research there is still much to be discovered about both fields. For data visualisation, a clear definition of what constitutes a visualisation is still not available and little in the way of formal structure exists to help data analysts create affective visualisations. Narrative visualisation shares these issues with extra emphasis on the lack of a clear definition for storytelling and narrative when discussing data science.

Chapter 2.3 – Virtual Reality

Virtual Reality (VR) has been a focus of research for many years. Starting with small displays and complex mirror setups over a hundred years ago to variants of a simple Head Mounted Display (HMD) system through the 1900's all the way up to the advanced technologies that exist today and are available to the public for purchase at reasonable prices. With so much history of VR technology and research it may be difficult to decide where it truly begins. While a majority of this research relies most specifically on the last five to ten years of advancements and research into VR for the purpose of this background the field of VR entered relevance around 1994 when the first wave of VR technologies was publicly announced and VR ‘hype’ [1] was at its highest. Within this chapter a thorough survey of research into the field of VR, since 1994, will be conducted. Focuses of this research will include the technologies that have been adapted to use VR and applications for VR that have arisen from it, what unique qualities VR introduces and what affects those qualities may have on future research, comparing VR systems to other available mediums including desktop displays and Cave Automatic Virtual Environments (CAVE’s). Finally, some existing research into displaying data visualisations as well as narrative elements through the lens of VR will be discussed.

Chapter 2.3.1 – Definition

Defining Virtual Reality can be difficult; as technologies have continually changed and focus has shifted from one application to the next more and more areas have become part of the overarching field of ‘Virtual Reality’. Fredrick P. Brooks, Jr., who wrote the paper “What’s Real About Virtual Reality” [1] in 1999 defined VR as “any [experience] in which the user is effectively immersed in a responsive virtual world. This implies the user [has] dynamic control of the viewpoint”. While it remains unspecified exactly what being “effectively immersed” means and how to measure it, the definition encapsulates most current fields that are defined in the field of VR and as such is a satisfactory definition for this paper. Fredrick P. Brooks, Jr. extends his definition by defining the required technologies for a VR system. The technologies he claimed were required included the visual/haptic/audio displays that immerses the user, the graphics rendering engine that generates ever-changing images at 20-30 frames per second, a tracking system and a database and maintenance system for building detailed and realistic models of the virtual world. An alternative definition from The Oxford Dictionary is “The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors”. While this definition is more specific and contains more details it also isolates certain more advanced technologies from this field. For example, the Leap Motion requires no gloves to track hand movements. The definition also states that interaction must seem real or physical which does not necessarily hold true for all applications of VR.

Chapter 2.3.2 – Virtual Reality Technologies

Virtual Reality has been a large area of interest for many years and as such has evolved and grown over time. When [1] was being written, Fredrick P. Brooks, JR. claimed that “more than

10 and less than 100" virtual reality installations that were actively being used for results. While that quote did not include both vehicle simulations and entertainment applications, both of which have become the largest areas for applications of VR since, it shows that even after its heavy hype in 1994 VR had still struggled to gain a footing. At the time of his paper, his survey of current technologies included VR systems built for:

- Vehicle Simulation: These systems were considered by Brooks to be the most advanced systems available at the time and have continued through until now as one of the most successful implementations of VR technology. The vehicle simulations allowed the training of users in complex machinery without the risk of damage and with the added advantage of being able to simulate situations that would be impossible to simulate using real vehicle testing.
- Entertainment: While it could be argued that modern advancements in HMD technology, lowering cost and ease of use of VR technology has made entertainment the biggest emerging field for VR, in 1994 there was limited applications for entertainment and most were found to be underwhelming or inapplicable for commercial use.
- Seismological and Architectural Design: Taking advantage of the spatial understanding VR allows some companies and universities had employed VR to allow analysis of seismological data in an attempt to understand earthquake behavior and damages. Similarly, some implementations included using VR to help understand and design architectural structure.
- Medicine: With similarly reasoning as that which lead to vehicle simulation technology some VR applications use VR to help train doctors and surgeons on procedures and complicated systems through the risk-free world of simulated training.

While not a complete list Brooks' 1999 survey of VR technology allowed a clear snapshot of what technologies were successfully and were being deemed useful for the time. However, as technology has improved and VR as an industry has become more accessible to be outside the research sphere more and more applications of VR have been tested. While all the applications mentioned above still exist and have been expanded upon and improved, new applications have been developed that take advantage of new technologies and methods of interaction.

Research has been conducted into many different attempts to adapt existing systems or technologies with virtual reality tools. Since the days of 1999 the possibly biggest change in VR application has been its shift in focus toward commercial use instead of industrial uses. With the recent release of the HTC Vive and the continued improved iterations of the Oculus Rift the publics has had access to more VR software and hardware than ever before. This coupled with a focus on creating easy to use development software for these technologies has led to video games becoming the forefront of new VR technologies. Despite this push towards the entertainment industry VR is still involved in a lot of industrial and educational work as well.

One paper [36] aimed to discuss how virtual reality and the paradigms and methodologies surrounding it could be applied to an application that intends to teach or educate the user base. This paper is particularly relevant to this dissertation as education the user on certain facts is part of what the virtual visualisations created intend to do. This paper began by discussing what qualities are unique to VR, namely the qualities immersion and presence. Both immersion and presence have become crucial areas of discussion in the virtual reality realm. To capitalise on these qualities this paper aimed to focus on the interaction as other studies [3, 29, 37] have found that interaction is a key quality in immersion and can have a higher impact on learning than the immersion itself. To see how affective interaction and other VR systems could be on learning programs the authors conducted a study. The experiment ran was a virtual environment that aimed to aid children of ages 8-12 in learning about mathematical fractions. To aid in the children's understanding the virtual environment chosen was a virtual playground. As opposed to Head Mounted Display technologies that are popular today this experiment was run in a CAVE environment. In CAVE's the user is placed in a cube shaped room with projectors lighting up every wall around the user, this in combination with tracking software allows the user to explore a 3D environment as if they were in it. Within this world the children were asked to construct simple objects that actually represented fraction problems. For example, one problem asked the user to increase the size of a swings set, originally sized 3x4 with 12 blocks. The user was asked to increase the size of the swings set while still maintaining a rectangular shape. By either adding 1/4 or 1/3 blocks to the shape. While completing this task the children were aided by a bird character that would give them advice and implore the children to discuss their logic and why they made the choices they did. The results of this study were interesting with the quantitative results showing no difference between the groups of children. In particular, the authors found that while the children still struggled in this 3D space to solve issues when supplied with support and visual/audio cues as to their success/mistakes the children were able to diagnose why their decisions were wrong and be able to not only then select the right choice but understand why it was the right choice. This observation suggests that the inclusion of the 3D virtual space allowed the children to use knowledge that is not connected to standard mathematics to understand the problem. This observation is consistent with a lot of learning strategies for mathematics. Due to the abstract nature of a lot of mathematics it can be difficult to understand what a certain formula or action is actually doing, or what a certain variable represents. As such teachers often try to give real life examples to problems to help with this issue. The inclusion of VR technologies allows the user to naturally use real world knowledge to help understand the problem.

Another paper that aimed to explore the power of VR was "Immersive Journalism" [38]. In this paper the authors aimed to explore the use of immersive journalism, the ability for the participant to enter a virtual scenario representing a particular news story, to enhance a news story and create a possible emotion connection between the participant and the story. Their study aimed to use the advantages that VR affords, whether it be through a HMD or a CAVE style system, to convey a news story or world event. The key value the study measured was what they called "Response as if real (RAIR) which closely maps to other definitions of presence and immersion. The example created using this VR system was based upon a "*stress based interrogation from Guantanamo Bay Prison*". Guantanamo Bay had been a subject of discussion, particularly in the United States, about possible methods being used within. While many publications ran news stories on this issue the authors felt that this example would be ideal for attempting to engage the audience and invoke both empathy and sympathy through a shared experience. To achieve this, result the experiment involved a user sitting in a chair and wearing a HMD. Other peripherals involved included wearing a headset to allow audio affects and a belt that tracked the users breathing and replicated that for the virtual avatar of the user. The actual VR environment was a small, dimly lit, room in which muffled sounds of interrogation could be heard coming from the nearby rooms. A mirror was placed in the room so that the user could see their virtual avatar. The virtual avatar was positioned in a stance which was intended to cause discomfort and pain as a way of interrogation. While no results were recorded, discussions were had with the users after the experiment. Many of the users claimed that despite knowing they were sitting comfortably in a chair they actually felt discomfort and pain as if they were sitting in the same stance as the digital avatar. Other participants felt alone, and stressed about the voices in the other rooms. These results suggest that the study succeeded in inducing a high level of presence and RAIF as the user was able to truly believe they inhabited the digital avatar. From this paper, it can be shown that immersive journalism is a promising new application for VR technologies and is enhanced with virtual realities unique properties and characteristics.

One of the earliest conceived applications of VR technology was for the treatment and aid of those who have suffered terrible events and as such have developed Post Traumatic Stress Disorder (PTSD). The goal of using VR to help these patients was through the application of Prolonged Exposure (PE). In PE, the patient is placed back into the environment in which the PTSD derives from and then, with guidance from a psychiatrist or psychologist, try to become more comfortable, alleviate some of the stress this incident caused and in some cases come to terms and accept what occurred. VR was obviously a promising field to adopt this treatment as it is increased immersion and sense of truly being somewhere would aid in this treatment. One paper [39] aimed to discuss one of these technologies VRET. Within this VR system the Doctor was able to load particular scenes and control some of the variables of events of the world the patient would experience. As the patient experienced the event through the safety of VR they would describe what was happening. This system was found to be very successful and consistently showed better results than imagination based PE. Due to its success, the system was eventually upgraded to run in a more modern engine (Unity) which would allow for more complex and realistic simulations to be built. The upgrade also included more built in simulations to better accommodate each patients unique experience as well as a better user interface for the Doctor to allow easier customisation and greater control. Despite it being primarily used for military based cases of PTSD the system originally found use treating different kinds of phobias as well.

Both Immersive Journalism and Educational programs are new and interesting applications of virtual reality but one field that researchers are beginning to combine with VR is Data Visualisation. Some researchers have considered that one way to solve the issues of massive, unwieldable data sets is to take advantage of the increased world space and immersion of VR. Introducing data visualisations into a virtual environment poses a few conceptual and technological questions to be resolved. When deciding how to display each individual point of data the introduction of glyphs has seen use [40]. Glyphs are objects that are displayed within the environment in which the properties of the glyphs (colour, orientation, size, shape and position) represent different variables. Glyphs are efficient as a multivariate dataset can easily be displayed through a single object. However as one paper discussed [40], it is more important that the data can be comprehended and not simply displayed. This again is a strength of glyphs as the patterns and trends that these properties can reveal are easily discovered by the human brain. An application of data visualisation within VR that incorporates glyph style objects is that of a weather system tool [41]. This tool used colour, opacity and shape to represent different variables of weather including wind, heat and humidity (Figure 10). The use of colour within this tool also lends to the importance of comprehension not just display as the use of human colour analogies helps the user to understand the data. For example, using bright colours (red, yellow and orange) for high temperatures and using blue to represent water and rain. Other papers that have attempted to combine data visualisation and VR include [42] in which related data was clustered within a 3D space for analysis and [15] in which research was done into possible methods of interaction and selection when viewing data in a 3D space. As with most VR applications interaction can be the most difficult and crucial factor to implement when creating data visualisations in a 3D space. This paper used cubes created by the user with a brush tool to allow the user the ability to grab any cluster of data by simply tracing a cube around that information. The use of immediate feedback in the form of selected data being highlighted as the cube is drawn allowed the user a clear understanding of how the system worked.

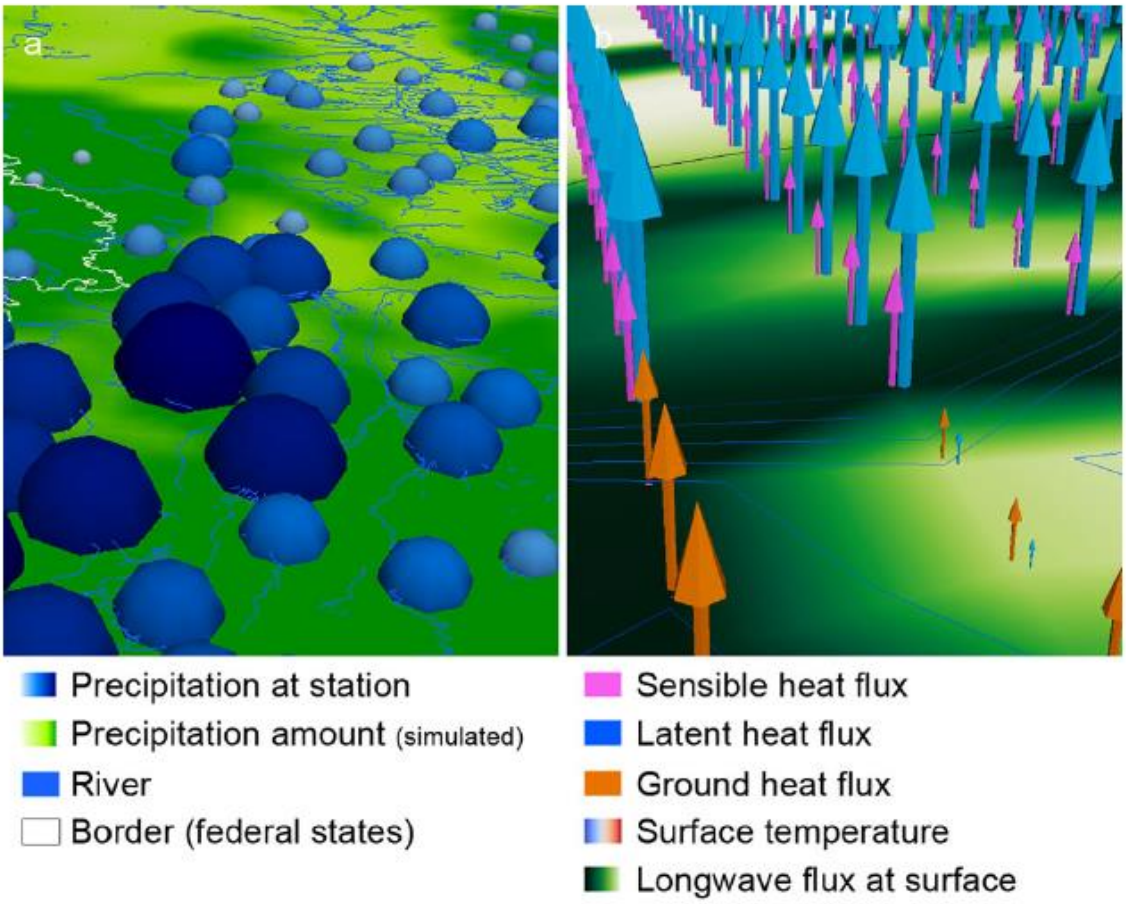

Figure 10 3D visualisation for showing precipitation data (a) and heat fluxs (b) [41]

Chapter 2.3.2 – Presence and Immersion

When discussing VR and the unique qualities it provides the two most important qualities that are always mentioned are presence and immersion. Presence in particular is believed to be the quality that allows virtual reality to achieve things no other medium is currently able to. It is so crucial to the success of VR applications that a questionnaire was developed to measure the presence of a user within a VR application [9, 43]. This questionnaire was designed to extract levels of presence, a subjective feeling [43], through four qualities:

- Control Factors: Degree of control, immediacy of control, anticipation of events, mode of control and physical environment modifiability.
- Sensory Factors: Sensor modality, environmental richness, multimodal presentation.
- Distraction Factors: Isolation, selective attention and interface awareness.

- Realism Factors: Scene realism and information consistent with objective world.

These questionnaires have been discussed and edited and debate still exists around how accurate they are and if presence can be measured as a quantitative or qualitative property. Despite these issues one of the most difficult parts of discussing and measuring both presence and immersion is being able to define these two qualities. Throughout the field of VR research many different definitions of presence and immersion exist. For example, one paper [8], defines presence as “the feeling of actually believing in the VR world around you despite knowing it is not real”. This paper agrees with the consensus that presence is subjective and is best measured through surveys and questionnaires [7-9, 43]. However, this paper also suggests possible alternative for measuring presence and expresses doubts that questionnaires are the best approach. Other possible measuring strategies included measuring brain activity, non-conscious physiological responses (heart rate or skin conductance) and other involuntary behaviours such as flinching in response to a nearby flying object. A similar definition for presence is found in [7] in which presence is described as “the sensation the user gets from what they are experience through virtual reality despite knowing that what they are viewing is not physically real”. By comparing these two definitions it becomes apparent that presence is the users’ belief of the world being presented to them, irrelevant or even despite, of it actually being real. This definition of presence matches closely with the goal of any VR experience, to immerse the user in a 3D experience, and therefore any VR experience can be tested by how much presence the user has while in the VR world (Figure 11). However, if presence is an all-encompassing measure of the success of any VR experience, what is immersion and what affect does it have on a user and the VR experience. [7] defines immersion as “the technical capability of the system to deliver a surrounding and convincing environment with which the participant can interact”. Comparing this definition for immersion with that of presence and the two major differences are that immersion can be measured as an objective quality and can be measured independently of each individual user.

Figure 11 Using virtual reality to recreate the rubber arm illusion experiment. Image (a) shows the user viewing a 3D model of their arm with the rest of the room in darkness. Image (b) shows her real arm. A tracked wand was used to simulate the sensation of touch being placed on her real arm. After a few minutes, most users react to stimulus of the virtual arm without any real touch. [8] (Image courtesy of Mel Slater et al.)

The paper claims that important properties of immersion include: Field of view, framerate and latency, tracking, realism and quality of rendering, and the number of sensory systems. Perhaps one of the most interesting differences between immersion and presence is the importance of realism and quality of the rendering. While immersion considers the realism of the scene, to what extent do the objects and interactions available within the virtual world compare to the real-world counterparts, important is has been showed that presence can be obtained and does not appear to be connected with the realism of the scene at all [7, 36]. In fact, one of the most powerful factors in producing high levels of presence in a VR experience, more important than immersion or realism, is sound and audio. In particular, it has been found that spatialized sound, sound that realistically originates from its source in 3D space, has a massive effect on a user's belief that they are really in the virtual space.

Chapter 2.3.3 – Summary

Virtual Reality promises to be a new and interesting medium for which both existing and new concepts will be adapted. Virtual Reality's unique ability to fill the user with a sense of presence allows it to be used to educate, rehabilitate and simulate more effectively than any technology currently available. Data scientists have begun leveraging VR's spatial capabilities allowing it to be used to express large and complicated systems while still be manageable and comprehended. Despite this little to no research has been done on implementing narrative visualisation techniques to take advantage of both the spatial capabilities of VR and leverage the increased presence of VR to create emotionally engaging representation of real world data.

Chapter 3 – Virtual Reality Narrative Visualisation

This chapter discusses the design of the major contributions to the field. The major contributions discussed in this chapter are a design methodology for creating narrative visualisations, as defined by E. Segel and J. Heer [3], with the purpose of persuading the viewer, a design for incorporating a set of meaningfully connected narrative visualisations in a 3D space. These contributions are then tested through a user study designed to measure the users' presence and interaction trends throughout the study. This chapter will begin with a description of the early concept design for the study compared with the final design decided upon before implementation. Followed by a discussion of the changes and reasoning behind those changes. The analysis will be followed by a breakdown of the technique for each contribution in this dissertation, ending with the detailed application of this technique for the user study. Finally, the research hypothesis and expected outcome of the study will be given. The aim of this chapter is to describe both a general case and a specific implementation of the methodologies that this dissertation offers.

Chapter 3.1 – Concept Design

The project was originally designed to be a brief summary tool, used by law enforcement and legal parties. The current process involves the user first collecting the datasets from open source locations, analysing the data and extracting useful information and then finally compiling these results in a condensed form. Those conclusions were reported in written form providing an argument that explains and validates their conclusions. Issues with this process arose as the medium for describing results and reason, even with included images and other supporting media, was limited and stripped both context and depth. From these issues a project was designed that focused on the final stage of this process, the development of a tool that would allow more freedom of design for the user removing limitations on media, allow for large data sets without overwhelming the viewer and construct narratives or explain thought processes naturally from the author to the viewer. When constructing a system that could accomplish this task the first major complications was the visualisation of possibly massive and complex datasets. In the use case of law enforcement attempting to convince a judge or official to allow a warrant it was conceived that hundreds of pages of social media recordings, travel and movement logs and receipts or transactions could be relevant. This was fundamentally an issue of big data visualisation and the research fields of both data and narrative visualisation held promise as a possible solution to this problem. The other concern was the limitation on an effective medium to tell this narrative through. Conventional paper or PowerPoint presentation lacked depth as well as the ability to engage with the viewer or allow interaction. From this issue the emerging field of virtual reality technology was chosen as a possible medium.

From this early concept design the first deviation came from the use case. The law enforcement use case had two concerns that led to it being replaced. The first issue arose from the complexity of the law and law enforcement procedures. In particular, the expertise required by the viewer, a judge or appointed official in this case, is very high. This would cause problems when it came to testing the final design as only those with the prerequisite knowledge and experience would be able to adequately understand and test the system. From this concern an alternative subject matter was discussed; an interactive visualisation that discussed different competing theories for the creation of the universe. This subject would allow discussion of a complex matter while still allowing an opinion or statement to be made through the visualisation as there are many competing theories for the creation of the universe including the big bang theory, oscillating universe theory, steady-state universe and more. However, this subject was also discarded for the same reason as the second issue with the original concept subject. The data and information required to prove or disprove either of the two subjects discussed already was beyond that of any normal person. In the case of the origin of the universe, highly complex algorithm and mathematical proofs would require explanation as well as other difficult concepts. For the original case a lot of the information would be through complicated logs of travel and patterns realised through analysis of social media. At this stage the criteria for an applicable subject matter was as follows:

- The topic must be complex enough that it requires some explanation and can offer alternative views.
- The topic must allow for opinions to be drawn and proven. These visualisations are not meant to simply inform but to also persuade.
- The topic must use content and decision making that is understandable without further education or qualification.

It is important to note that these restrictions are only required for this body of work due to limitations of time and resources and could be removed or adapted given a greater scope.

Based off of these restrictions and third and final subject matter was discussed and finally approved. Gun control, specifically in the United States of America, and its effect on gun related crime was the final chosen subject. This subject fits all the criteria set above as it has a wide range of factors that may or may not affect the outcome, is a highly opinionated and controversial subject allowing a persuasive case to be made and use simple statistics involving everyday objects and concepts requiring minimal previous education or expertise on the subject. The final property of this subject was that the topic was currently relevant and was an emotionally charged debate. This quality meant that creating an emotional connection with the viewer would be easier. With the subject matter chosen an opinion then had to be decided on. For this project it was decided that the opinion to be proven was "Stricter gun control will have a positive impact on gun related deaths in the U.S.A". This position was chosen randomly and was simply an opinion used to test the hypothesis of this paper.

Chapter 3.2 – Narrative Visualisation Design

This section contains a description of the process and underlying technique for designing a narrative visualisation, specifically in the format of a data video [10], that aims to persuade the viewer of a given point. The end of this section will contain a detailed example of an implementation of this technique used in the final prototype for the user study. The visualisations designed in this section are expected to have minimal to no interaction just like normal data videos. However, multiple data videos could be used to create a sense of interaction.

Chapter 3.2.1 – Design Stages

When designing a visualisation with narrative elements a set of defined steps were developed:

- Data collection: Depending on criteria for visualisation this step may be optional.
- Data Analysis/Narrative Construction: At this stage, useful information should be selected. Possible narrative threads can be discovered at this stage.
- Modelling Data: At this stage the information has been collected and the method for display should be chosen.
- Narrative Integration: Implement the narrative components.

In this next section a detailed description of what each stage entails will be given. After this an example from the final prototype will be used with specific mention to what happened at each of the four stages of the development. The aim of this section is to allow for a narrative visualisation data video to be created with any topic.

Data Collection

The first stage involves collecting the data to use for the visualisations. The exact quality and source of data collected may differ depending on the needs or expectations of the data to be used. For general purposes, open source information or data that has already been analysed may be used instead. At this stage of the design any information that has use should be collected as no clear narrative or goal should be defined at this stage. During this stage the author may notice trends or constants in the data. These trends could possibly be converted to narratives in the third and fourth stage. There are many different rules and strategies to successfully collect data, using cited and reliable sources however data collection is not at critical stage of this project. For this project information was gathered through visiting web pages that had pre-analysed data. In an attempt to receive a balanced sample of data websites from both sides of the gun control debate were selected.

Data Analysis/Narrative Construction

At the second stage, all of the data gathered should be compiled and analysed. If the data collected at the first stage was already analysed and summarised, then only narrative construction is required. Narrative construction involves finding narratives or possible narrative elements from the analysed data sets. While defining a clear definition for a narrative or narrative elements is difficult, this methodology defines it as any of the following:

- A dataset in which a story can be extracted: For example, datasets that show increased temperatures related to carbon emissions can be represented by a story of the planets decline into pollution.
- A dataset in which the data can be symbolised or used as part of an analogy to symbolise images or concepts from the world: Using the same example as above the increased planet wide temperature could be represented by an increasing red hue over the planet's surface. In this case the analogy is how red is commonly associated with heat and temperature.
- A dataset that can be visualised as to create an emotional connection. These are more powerful examples of the previous datasets in which through symbolism data is represented with the express purpose of causing an emotional reaction from the viewer. With the same example representing decreasing populations as a series of endangered animals fading away can represent the percentile decrease of population while deliberately causing an emotional reaction.

Modelling Data

Once the data has been analysed and each possible dataset has been checked for narrative capabilities the visualisation method of the data must be decided. The first step in this stage is to decide on what equipment and software will be used to design each visualisation. This stage is similar to modelling when creating a data visualisation. Each dataset must be represented through a graphics technique, these range from new and novel concepts specific for the dataset or narrative to standard form of visualisation, including charts (bar, line, pie). This stage is open ended and can differ from one design to another. While not specifically a part of this section considerations for interaction and display, methods should be considered here.

Narrative Integration

This is the final and most important stage. By now each individual visualisation should have been built. Each visualisation should be grouped by a narrative thread. This could include a variety of factors including data, tone, timeline and message. Once each visualisation belongs to a narrative thread the data video should be designed. This stage is best compared to the storyboarding of a novel or film. The structure is crucial and the visualisations should follow logically and create a natural story arc. A crucial part of this stage is the incorporation of all elements that do not pertain to the dataset itself. This could include adding interactions, music or audio cues and any other narrative structures into the visualisation. If during this stage a particular visualisation does not fit or cannot logically be placed before or after a part of the narrative, consider going back to the second or third stage and recreating the visualisation to fit with a different narrative or more closely follow the current story. At the end of this stage a set of modelled visualisations, that contain narrative elements, should have been combined into a data video that tells one concise story.

Chapter 3.2.2 – Practical Example of Narrative Design

To understand this process more clearly an example data video that was created for the purpose of the final product will be deconstructed. The data video selected was called “Suicide Rates and Gun Control”. This visualisation was created to discuss the connection between guns and suicide rates throughout the United States of America as it is often a topic that is avoided when discussing gun related risks. This visualisation was chosen as it contains one single narrative, uses symbolism to explain the statistics and evoke an emotional response, and was created using only two statistics. This final point is worth mentioning as the inclusion of narrative visualisation techniques can extract a stronger emotional response and convey more meaning than a simple data visualisation.

The first stage of creating a narrative visualisation is **Data Collection**. For this specific visualisation the statistics were gathered as part of a web article that contained a set of data visualisations about guns and what affect guns have on different parts of society [44].

The next stage was **Data Analysis/Narrative Construction**. As a majority of the statistics gathered for this project were gathered from websites and journals the data had already been analysed and trends had been discovered. At this stage the statistics were grouped be relevance, any connecting factors including changes over time, similarities in location, similarities in gun control laws or statistics that could be built into a narrative. Within this stage, two statistics were discovered and grouped, claiming that other forms of suicide including cutting and poison has a 7% success rate whereas guns were successful in causing death a majority of the time. Further analysis of this articles sources revealed that there was an approximate 96% success rate in gun related suicide attempts. These statistics were promising in their capacity to constructed into a narrative as the statistics were related to a controversial and emotional issue.

After suicide statistics had been chosen the data went through **Data Modelling**. To model the statistics an online infographics generation tool was used. The specific tool used for this project was GoAnimate [45]. This tool was chosen as its style and functionality aligned with the intended look and feel of the intended final visualisations. Once the tool had been selected the information had to converted from a statistic to a visualisation structure. Which structure used varies on the intended outcome of the visualisation and the data available. For this visualisation, it was important that the data be represented in a symbolical and impactful way and the data had been displayed in a percentage. To combine both of these traits an alternative approach to a pie chart was used. In this chart, instead of representing a percentage of a circle the visualisation instead shows a percentage of symbols. The method of differentiating the symbols can differ from colour changes to completely different symbols. In total three different visualisations had to be created in this structure. One that represented the entire set of symbols, unaffected by the data, and two visualisations representing the dataset with and without gun access.

Finally, with all three visualisations modelled the final step was to introduce **Narrative Integration**. At this stage, both the narrative structure and symbolism must be decided and implemented. For this visualisation, it was decided that the entire group visualisation would represent twenty people. To represent each symbol as a person an animation of a heart rate monitor was used. This symbolism allowed immediate recognition of a human life as well as allowing for a natural progression between the two states, alive and dead. After the symbolism was chosen the visualisation had to be ordered. Using narrative trends often found in film it was decided that the best way to start the visualisation was with the unaffected data, showing 25 heartbeats (Figure 12).

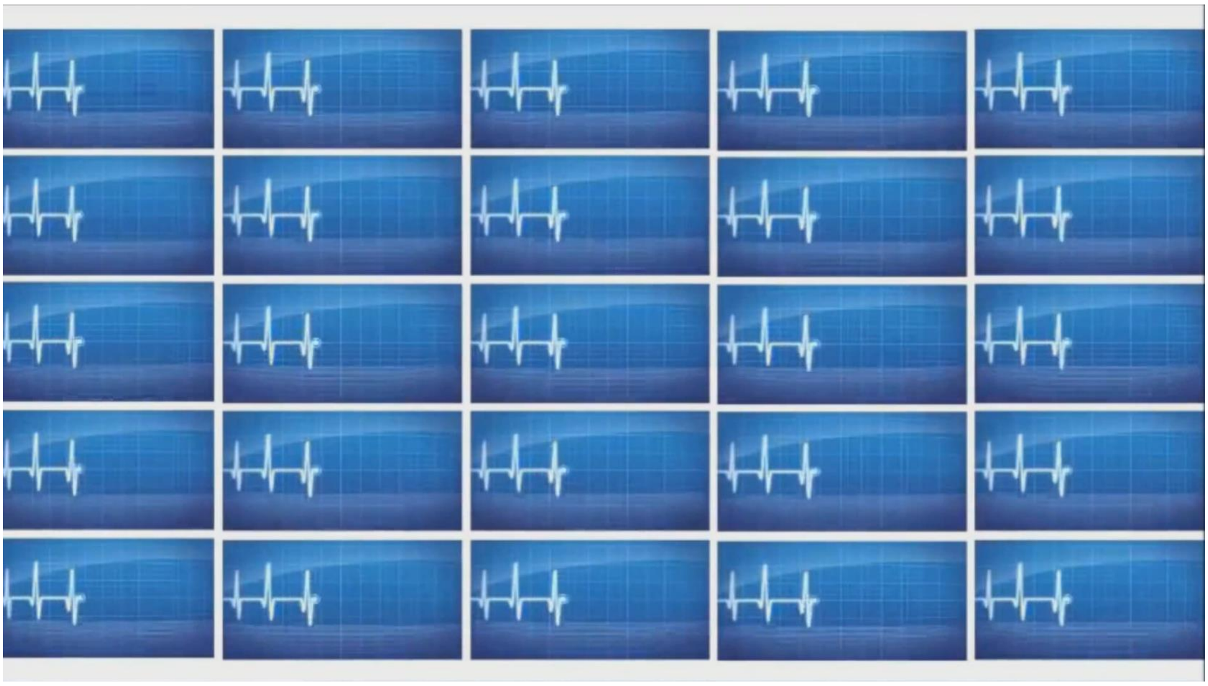

Figure 12 Suicide visualisation showing all 25 heart rates.

Following this the statistic of 6% mortality rate for non-gun related homicides was represented by a short animation of a number counting up to 6. This same animation was used again to represent the gun related statistic of 96% later in the visualisation. The repetition allowed a second method to show the disparity between the two values. As in the same space of time the 0 to 96 counter went through far more numbers than the less lethal 6 counter. After the counter was the visualisation of the 25 heartbeats after all using non-gun forms of suicide. This visualisation showed one of the 25 heartbeats had flat lined. To emphasise this point, over the course of the animation the camera focused and zoomed on this heartbeat. Following this was the 96 counter, and the visualisation for the 25 people after attempting suicide using guns. In this visualisation, only one of the 25 survived (Figure 13), as opposed to the non-gun visualisation where only one flat lined.

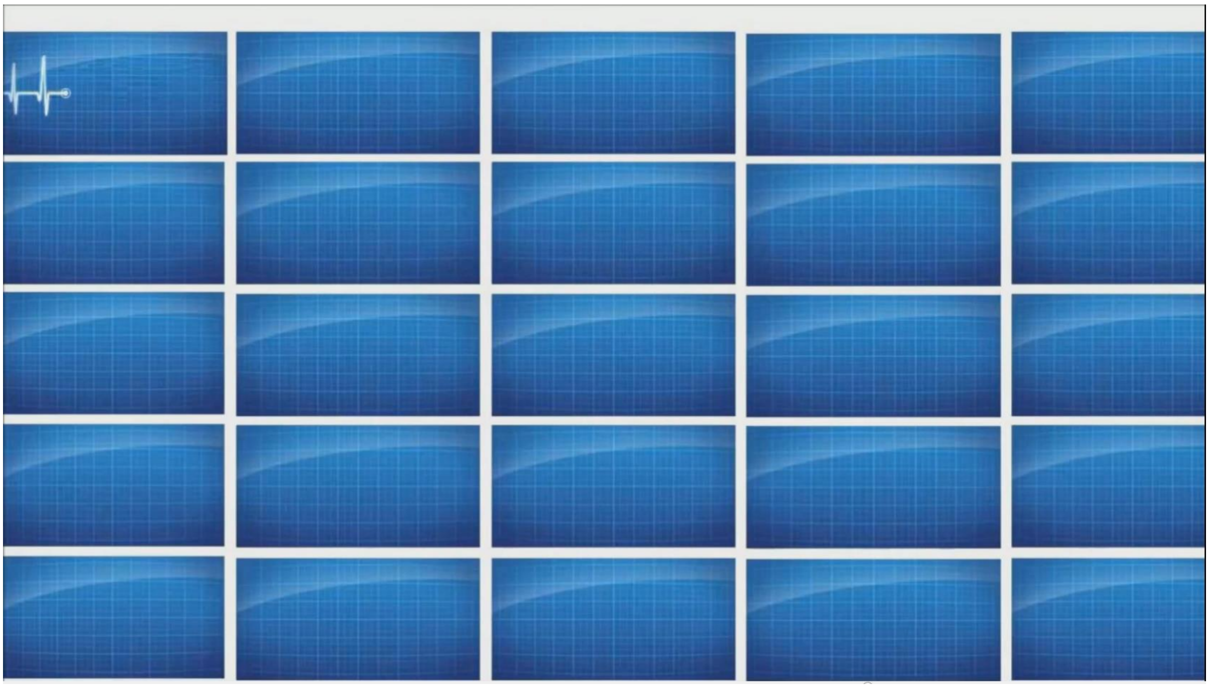

Figure 13 Suicide visualisation showing only on survivor of a gun related suicide attempt.

The symmetrical nature of this result was the reason for specifically 25 heartrates. Similar to the “non-gun” visualisation the “with guns” visualisations zoomed in on the one survivor, to emphasise the result. At this stage, the data has successfully been visualised with a narrative structure, but to end the narrative a message or opinion should be stated. To accomplish this the initial visualisation is displayed again. This technique mirrors a technique in other narrative genres to begin and end with the same image. The final addition to the visualisation is the audio output. While no music was added, a narration was used for each stage of the visualisation. This narration simply described the visualisations as they appeared and was generated using a text-to-speech voice emulator. In the final visualisation, the voice recording was used to summarise the method of the visualisation, in this case that the intended goal is for there to be no successful or even attempted suicides while also stating that the removal of guns is one step towards this goal.

Chapter 3.3 – Virtual Environment Design

This section discusses the design of the 3D environment in which the narrative visualisations were placed and structured. This section focuses on the specific implementation for this process and was designed to work with these visualisations specifically.

Chapter 3.3.1 – Selecting Technology

The implementation and strategy employed to design the virtual environment was heavily affected by the available technology. As such to understand some design choices an explanation of the different technical elements must be discussed.

For the virtual reality hardware, the HTC Vive was chosen. The Vive is a virtual head mounted display (HMD) that tracks head movement in six degrees of freedom (Figure 14). The Vive also implements two 'lighthouses' which can be placed in a room to allow tracking of the headsets position. The final piece of hardware the Vive offers are two controllers (Figure 15). These two controllers are tracked in real time just like the headset. The controllers are identical with a trigger, two side buttons, a menu button and a touch pad that also acts like a button. With all this technology, the Vive is perhaps one of the least limiting HMD systems available and as such was a preferable choice for this project.

Figure 14 HTC Vive headset

With the HTC Vive being the chosen hardware, the software engine in which to develop the program was selected. The Unity Engine was the final choice for game engine due to a particular set of qualities:

- Unity is free to use and only requires a license for publications of the software.
- The Unity engine has a SteamVR plugin which is designed for simple drag and drop implementation of the Vive system.

These advantages immediately highlighted Unity as the preferred system as it removed the complexity of combining two different systems of software and allowed more focus to be placed on the project itself.

Figure 15 HTC Vive controllers

Chapter 3.3.2 – Technology Limitations

Despite the advantages of the Vive system and its comparable flexibility to other hardware choices the limitations of current systems, Vive included, led to some sub-optimal design choices.

The first limitation arose from the controllers. The Vive controllers allow for a variety of custom inputs but are the only tracked forms of interaction allowed. This removed the possible of implementing a hand tracking system like the LEAP Motion Controller. LEAP had been considered as a more adaptive and natural form of interaction but was ultimately avoided due to the Vive architecture. Another design decision that was made based off of the controller was in assessing assumed knowledge of the Vive. While the use of hand interaction or a standard gaming controller would have required some instruction the Vive controllers were unique and would require a detailed explanation for the participants of the study to understand.

Secondly, the architecture and layout of the virtual environment was heavily influenced by the Vive HMD's capabilities. The Vive, theoretically, allows massive areas of freedom for movement in tracking. However, the area where the project took place was limited to only a few metres square for movement. Due to this limitation, a decision needed to made as to either create a virtual environment of a similar size to the available space or to implement navigation techniques to replicate a larger area while still only requiring a few real metres of free movement. The decision was made to make an area of similar size as having a large environment was not crucial to the visualisations or to the feeling of presence this experiment aimed to exhibit (Figure 16).

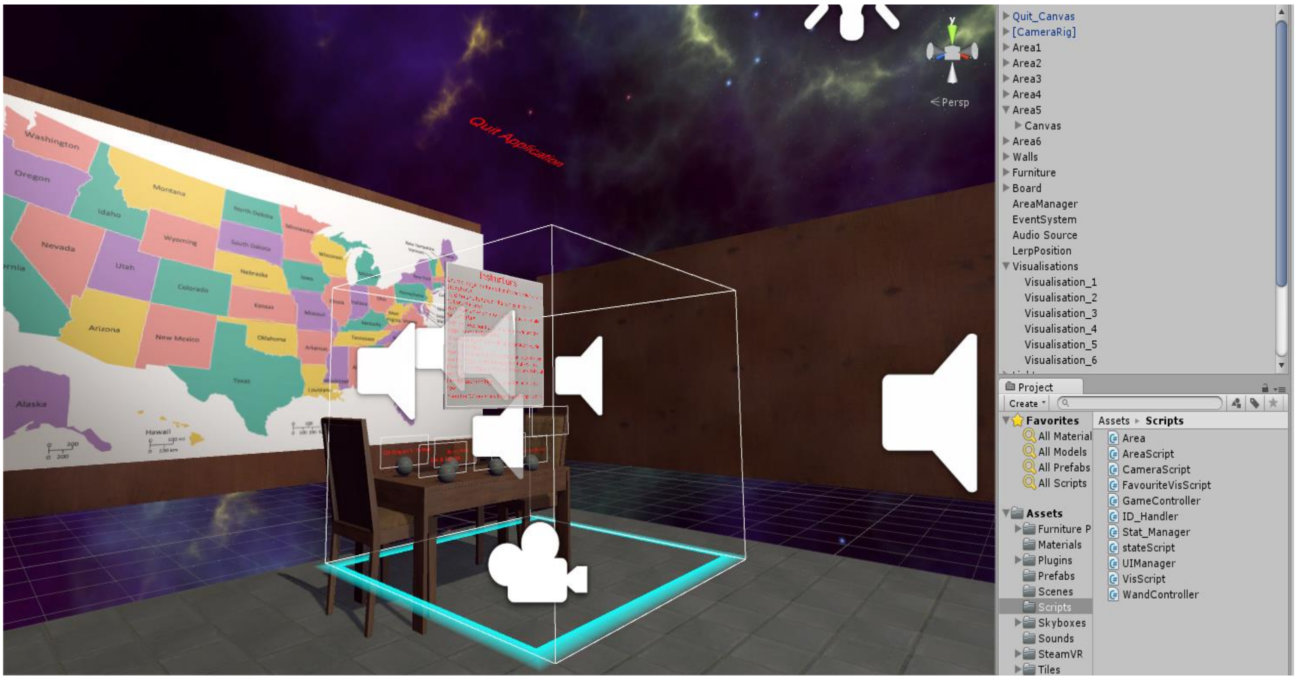

Figure 16 Unity Engine view of 3D environment

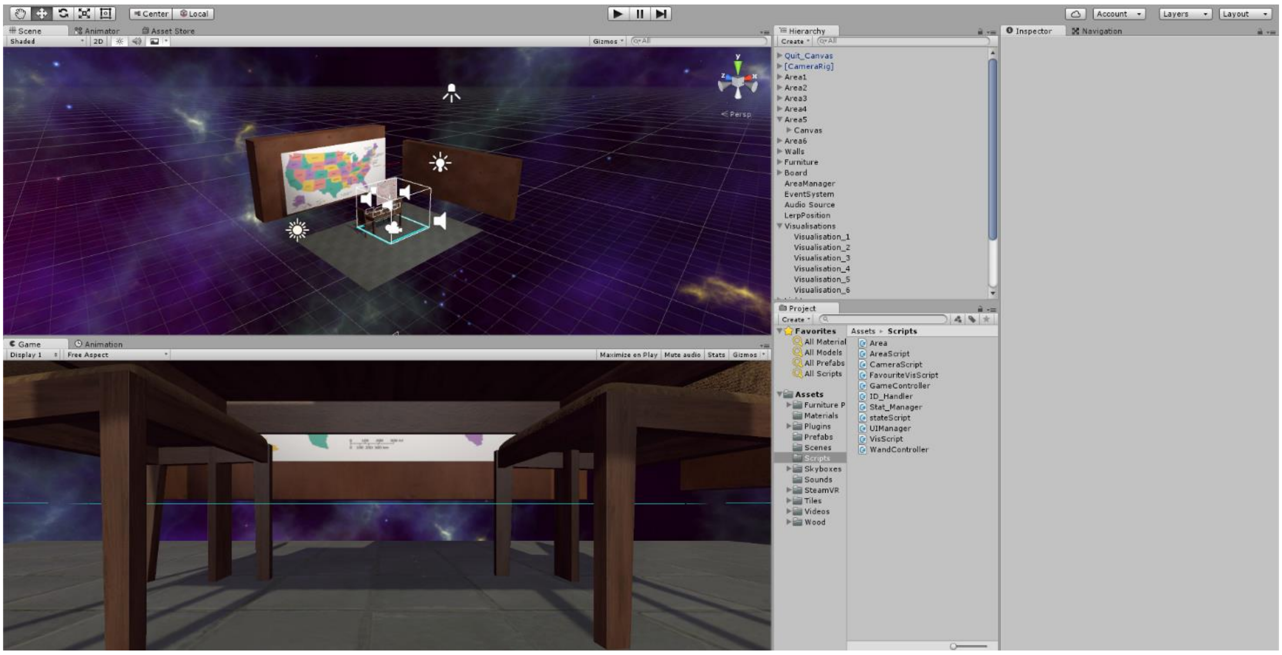

Figure 17 Virtual Environment being designed

Chapter 3.3.3 – Environment Design

The technological limitations had influences on both the layout of the scene and the interaction methods available. The other design decisions, however, were focused on creating a logical and symbolic environment in which the narrative visualisations could be viewed and considered.

The early stages of development for the virtual environment produced a set of requirements for the system:

- The user should be allowed free movement at all times. This includes all kinds of movement inclusive of head and controller movement.
- Similarly, control should never be taken away from the user. This design decision was crucial as it was found that moving of the virtual avatar caused disorientation and sometimes even motion sickness in the user.
- From the initial display the user should have an overview of the system. Being able to see all intractable elements immediately. This architecture would closely follow the inverse of the Martini Glass structure or the Drill Down Story [3], in that the original view is open ended and with user interaction becomes more focused.
- Both narrative visualisations and more simple data visualisations will be present in the virtual space.

- The ability to highlight or ‘favourite’ any visualisation that the user felt was relevant or impactful. Later design choices also led to the incorporation of a final screen in which all selected favourites could be viewed.

From these requirements, the project went through a rapid prototyping stage in which elements and concepts were considered, accepted or rejected, and then reconsidered. It was felt that this approach was more applicable and natural to the development of an interface and environment in which a user must interact. Despite this rapid prototyping technique there was little to no user feedback given throughout developed. As such the final study is also the first introduction of the project to real users.

Another consideration was the parallel design process of the visualisations and the virtual environment. Normally the visualisations or the environment would be developed first followed by the other component. This would ensure that both components would fit together and work both structurally and thematically. However due to time constraints this was not possible. As such the virtual area was developed with an intentionally modular attitude towards visualisation structure as the exact design of the visualisations was unknown.

Figure 18 Live updating list of visualisations the user has 'favourited'.

The virtual area was designed to be structured such that the user was able to interact with the visualisations and consider the possibly difficult decisions and concepts that arose from the topic. As such the focus for the aesthetic and theme of the actual environment was to not be distracting by being overly designed or under developed and confuse the user. With this in mind the virtual area's theme was deliberately abstract. An abstract design meant that no analogy to a real-life location or concept should be apparent, to achieve this the area explore able area was placed in what appeared to be the middle of space. Using a space skybox also avoided any feeling of enclosed space that rooms could often exhibit in a virtual world. With the skybox and theme decided on the next step was to add the backdrops and locations for the visualisations. For the data video a simple table and chair was placed in the centre of the area. Two wooden billboards were placed in the scene, one directly to the front and the other on the right side. These two billboards were intended to be used for any additional data visualisations added and for keeping track of the visualisations the user had selected throughout the experience (Figure 18).

The final element of the scene was a quit button which was placed above the scene as to not be accidently activated prematurely. Upon activating this button, the user is taken to a separate room, which has a similar setup to the first. In this room, a narrator shows the user the visualisations that they chose as their favourites as well as the ones selected by the author (Figure 19). The narration asks the users to compare these choices. At which point the experience has ended and the user may leave.

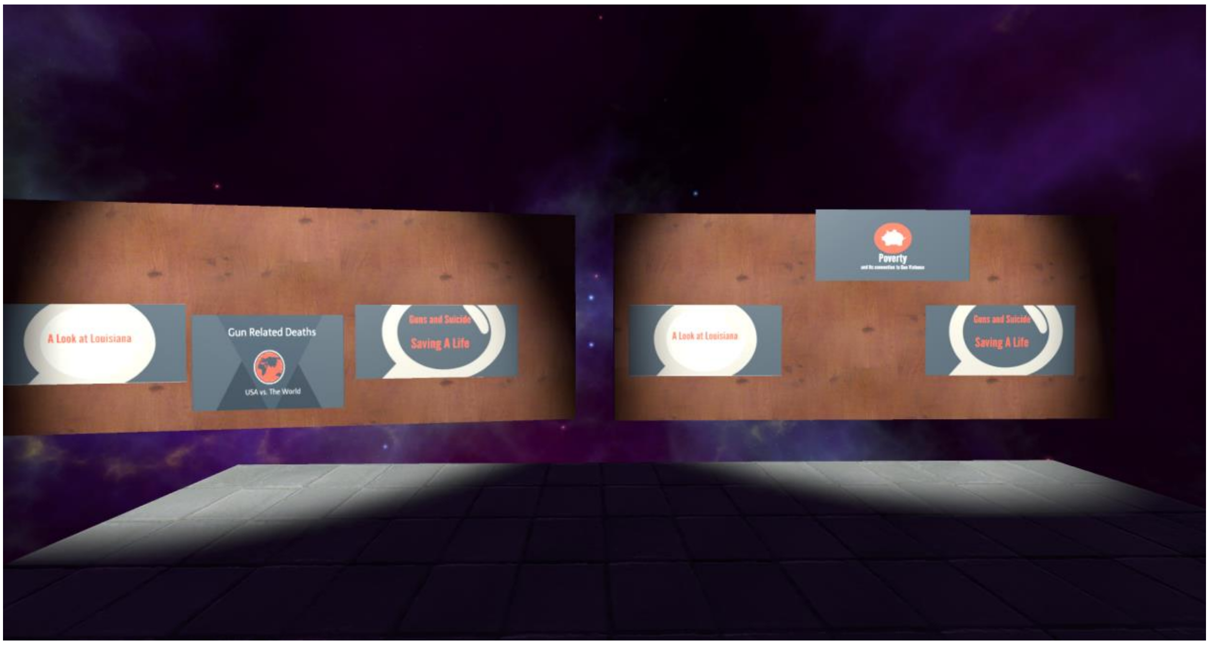

Figure 19 Final scene shows users choices (on the right) and the authors choices (on the left).

Chapter 3.3.4 – Visualisation Implementation

The modular visualisation structure of the virtual environment led to the design of "Area Spheres". These spheres were simple grey orbs that were chosen to deliberately have no symbolic representation to store each visualisation or set of visualisations. At the early stages when the exact design of the narrative visualisations was unknown these spheres had been designed to attach themselves to the user avatar upon activation and then to display the visualisations around the user. In the final design these orbs, upon activation, float to the centre of the virtual environment and then activate the data video attached to it. To help the user understand what each orb represents, each sphere was given a brief title that summarised the theme or message of the data video held within.

Figure 20 Burglary Rate visualisation being played in 3D space.

The next step in implementing the visualisations into the virtual world was to place the data visualisation onto the large wooden billboard behind the table. The data visualisation created for this purpose was an interact able map of the United States of America (Figure 21). Unlike the data video visualisations available on the table this visualisation was deliberately designed to state the statistics with no narrative elements. In this visualisation, each state, upon selection, would display a set of statistics about the state in regards to gun control. The information available was the percentage of gun ownership within the state, the amount of murders committed per 1,000 residents, and the amount of gun related murders committed per 1,000 residents. Another canvas was added with the purposes of listing the instructions to the user. Unlike all the other visualisations this one is not grounded to the scene and disappears completely once the user choses to stop reading it. The instructions however, can then be reintroduced through the press of a button.

Figure 21 Data Visualisation of United States of America map. With data in bottom left.

Implementing the narrative visualisation data videos into the virtual scene was the final step. The simplest solution was to simply place the videos onto an object into the scene. Doing this allowed the viewer to manipulate their viewpoint to see the video from different angles and even view it from behind. An alternative implementation was to create a billboard affect by having the visualisation follow the users gaze. This implementation was discarded as it detracted from the freedom and realism that the virtual environment provided.

Chapter 3.3.5 – Interaction

With the visualisations complete, the virtual environment designed and the visualisations added to the world the fourth and final stage is the implementation of the interaction techniques to select, favourite and view the visualisations available. Up until now both versions of the visualisation developed, desktop display and HMD, have followed the same design. Obviously, interaction is the area in which the differences of the two mediums is apparent and as such both the desktop and HMD have different mechanisms. This section describes the forms of interaction developed for each medium.

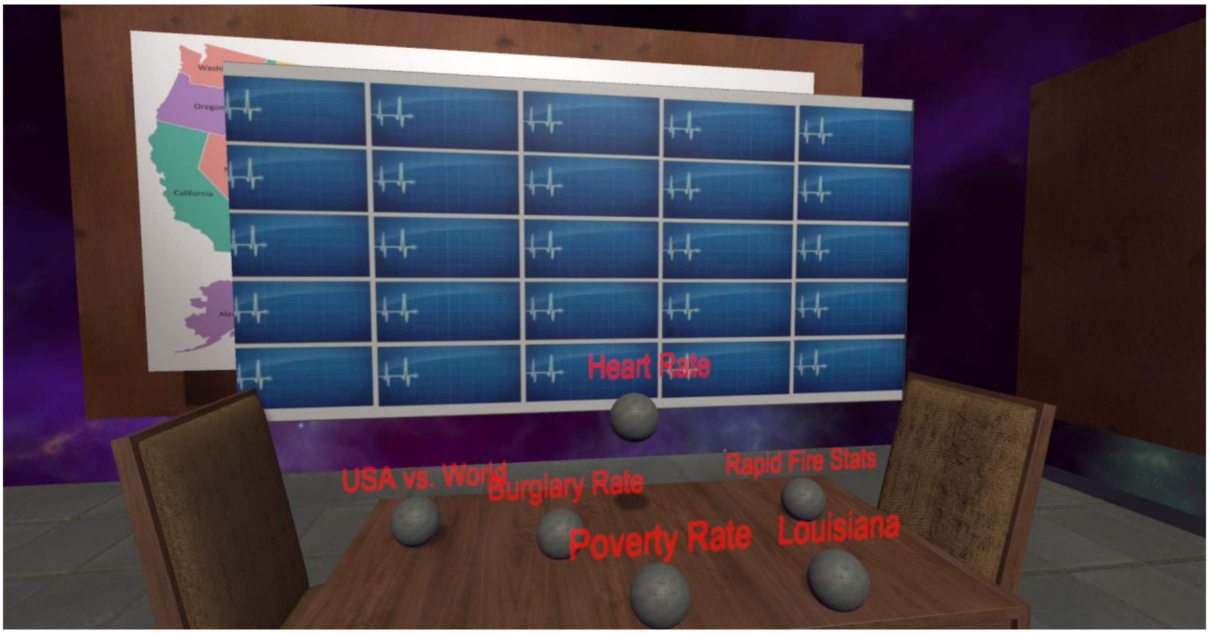

Figure 22 Suicide visualisation being played in 3D space.

For virtual reality, movement of both the avatar and the viewport was handled by the HTC Vive’s tracking system. The user could simply move around or turn their head to exhibit the same response in the virtual world. If the user at any point was reaching the edge of the safe area for movement the Vive automatically showed a light blue grid to indicate that movement in that direction was no longer safe. This precaution was strengthened by a deliberate design to make the walkable area within the virtual world match the size of the real world as closely as possible. All other interactions are handled by the Vive controllers. Upon starting the experience one of the two controllers is assigned as the main controller. This controller has two unique properties from the other controller (Figure 23).

Figure 23 Vive controller in virtual space behaves just like it does in the real world.

The first property allows the controller to be placed into any of the "Area Spheres", then activated by using the trigger, to start playing the attached data video (Figure 21 & 22). The second property is activated by squeezing both of the side buttons of the controller. When this is done a laser is shot out from the end of the controller and can be used like a laser pointer. This laser pointer can then be aimed at interact able elements in the scene and activated by pressing the trigger. This laser could be used on the instructions, to make them disappear, the data visualisation of the U.S.A to display its information above the other controller and on data videos to add or remove them from the favourites billboard (Figure 24). Finally, the laser can be activated on a quit button, visible above the scene, to exit the main area and enter the final visualisation.

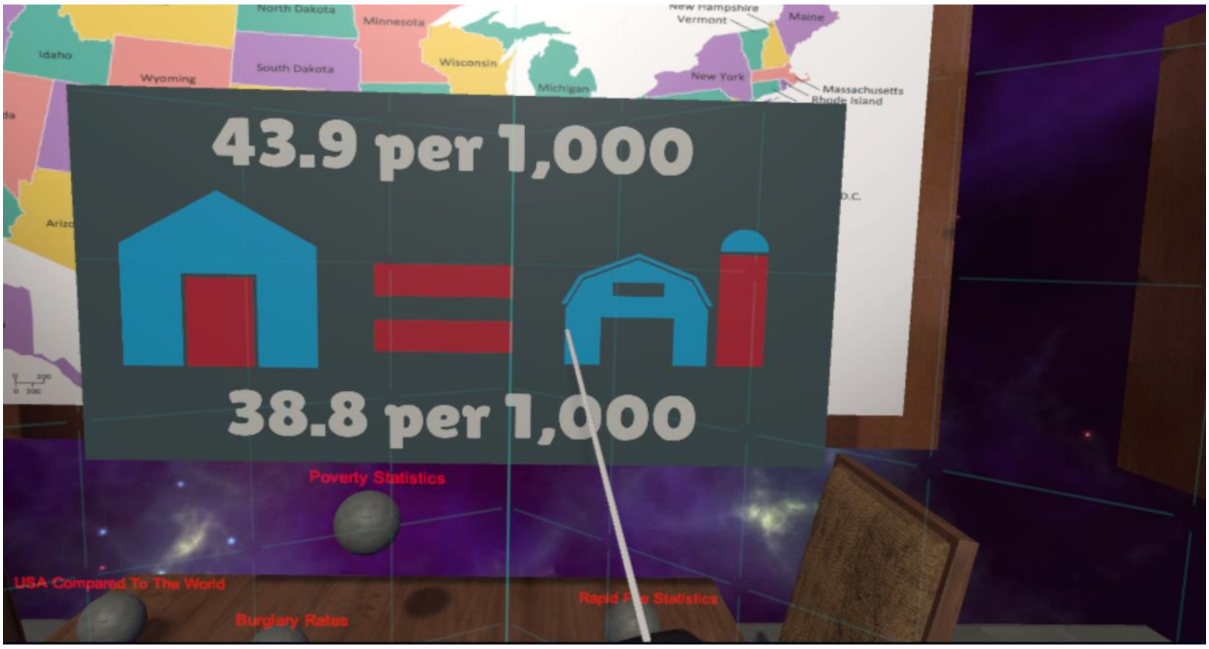

Figure 24 Using the laser, the user points at a visualisation to favourite it.

For desktop, the first choice was how to integrate movement, both the physical movement of the character and the rotation of the viewport. Existing experience in video games, specifically first person shooters, was used. The character would move their head with the mouse and could walk forward, left, back, and right with W, A, S and, D keys respectively. For all other interactions, similar methods were used to the virtual reality interactions. The laser is activated using the right mouse click. The only other change is how a "Area Sphere" is activated. While moving the physical controller into the sphere is the method chosen for HMD, for desktop the laser must be pointed at the sphere and then activated.

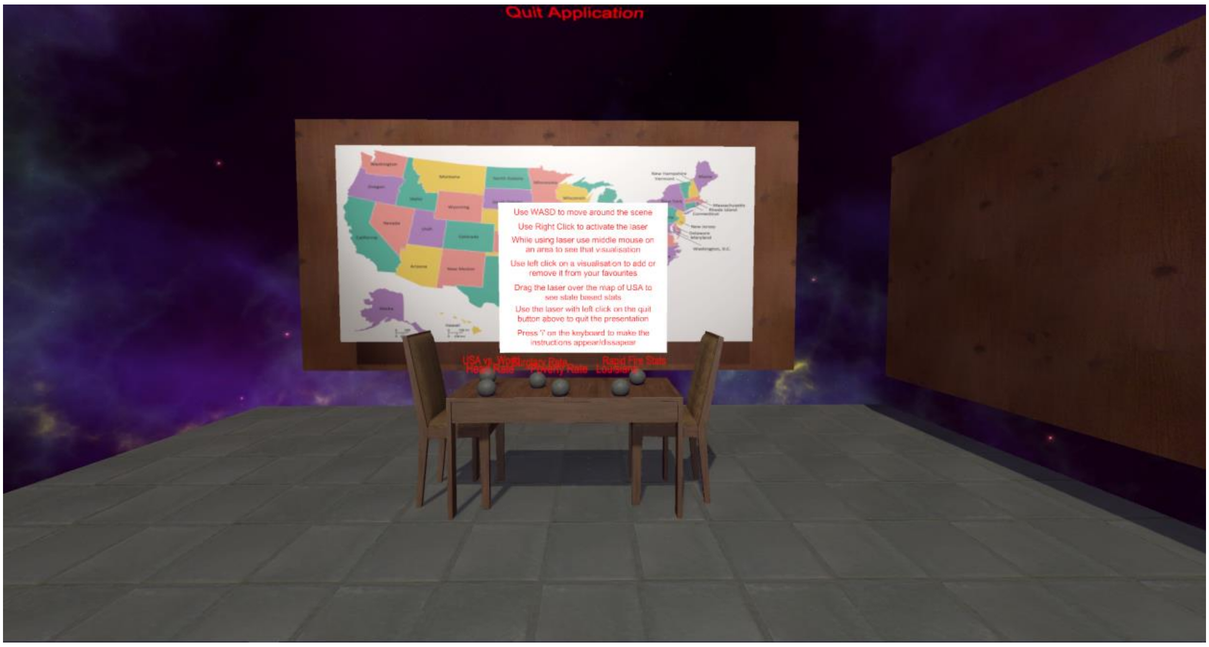

Figure 25 Initial view upon entering scene.

Chapter 4 – User Study

To evaluate the effectiveness of the narrative visualisations developed and the presence of the virtual environment compared to that of a desktop display, a user study was conducted. The user study was designed to give feedback in the form of a questionnaire and to deduce which medium had a more positive result through data recording throughout the study.

Chapter 4.1 – Study Design

The primary goal of the study was to prove that the use of virtual reality technology, specifically head mounted display (HMD), would enhance a visualisation based experience compared to that of a standard desktop display. The secondary goal was to evaluate the effectiveness of narrative visualisations to persuade or inform a user through both of these mediums. To evaluate these two statements, two separate forms of output were generated from the study.

The first is a questionnaire aimed to extract both levels of presence the user felt throughout the experience as well as a smaller set of questions focused on the narrative visualisations and how they responded to the experience as a whole. This same questionnaire was asked to both the users that used the HTC Vive and those who experiences the visualisations through a desktop display. In total the questionnaire contains 17 questions. The first five were created specifically for this study and focused less on each visualisation individually and more as an entire experience trying to convince them of a particular opinion. The second half of the questionnaire is a subset of the B. Witmer and M. Singer presence questionnaire [9] used by M. Slater in his paper [43] questioning the validity of the original questionnaire. This subset was chosen as it covered all of the categories required to measure presence; control, realism, distraction, and sensory, while avoiding asking too much of the user. While these results may not be indicative of a definitive measure of presence it should work as a guideline for comparing presence between the two mediums.

The second are a set of number variables that are recorded throughout each users' participation in the study. These numbers will form the base of the results discussion with the questionnaire being used as a secondary source of discussion. The number variables are recorded throughout the entire time the user is in the environment, starting from when they are first left and finishing upon exiting the program.

The study involves two groups. The first group, named “Desktop”, experience the study through a standard screen display. All interactions and navigation is completed from a keyboard and mouse. The second group, called “Virtual Reality”, experience the study through the HTC Vive display and use the Vive controllers to interact. All movement is handled through the inbuilt tracking system allowed through Vive with the headset, controllers, and lighthouses. Both groups experience the study indoors within the same room.

Chapter 4.2 – Demographic

Specific demographics regarding gender and age were not recorded excluding a requirement of being between the ages of 18 and 40. However a majority of the participants were male with only 4 females participating. A majority of the participants had high computer experience, with over half having had experience virtual reality technology in the past. The study included a total of 30 participants with 15 being chosen for each group.

Chapter 4.3 – Study Methodology

For each participant, the user study begins with a review of the participant information sheet (see Participant Information Sheet in Appendix A – User Study Resources), this form describes the study briefly and goes over the aim of the study. This form would have already been shown to the participant earlier through email correspondence. Once satisfied the user would then sign a consent form (see Participant Consent Form in Appendix A – User Study Resources), the user is guided into one of two areas of the room. A divider was placed between the two areas to help create a sense of privacy for the user during the study (Figure 26). Creating this safe area was a priority particularly for the Virtual Reality group of the study as the combination of headphones and headset left the user isolated from the real world around them. What hardware would be used was chosen using an alternating pattern to assure that an equal number of participants were found for each group. At this stage the context around the study was described. The participant is told to consider themselves a person of interest in an upcoming vote to introduce stricter gun laws in the United States, users were asked if they were aware of gun control and its significance in the U.S. After this the user was placed into the headset, if in the “Virtual Reality” group, or asked to sit by a computer with a set of headphones on. For the rest of the study the user was alone and explored the visualisations.

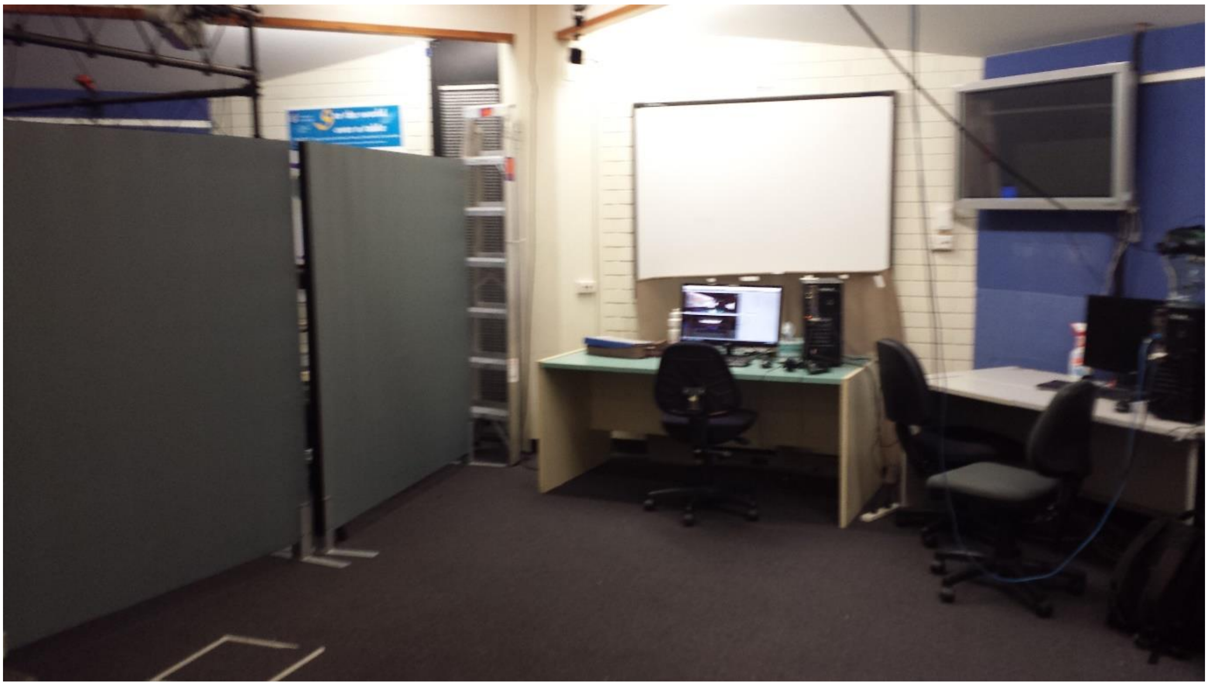

Figure 26 Study Room - Explorable area for HTC Vive users

Following the end of the experience the user was asked to fill in a short user (see User Questionnaire in Appendix A – User Study Resources) asking a series of questions relating to their experience and levels of presence throughout. The majority of these questions focused on their presence and how they felt about interactions different elements of the study. Finally, the user was able to add any comments or suggestions that they felt were not expressed by the questionnaire.

Chapter 4.4 – Visualisations

For this study six separate visualisations were developed using the techniques described earlier in this dissertation. A short description of each of these visualisations will be given.

Visualisation 1

The first visualisation is designed to list of statistics related to guns in the United States as quickly as possible. It begins with a bar chart comparing accidental deaths using guns in the United States compared to other countries. This graph was chosen as it reveals that the United States has double its closest rival. The second visualisation is similar, showing another bar graph of homicide rates using guns across the world. This visualisation compares the U.S. to war torn countries like Afghanistan and Iraq, which reveals similar rates to the U.S. The next visualisation highlights multiple statistics. Each statistic starts in the centre focus before shrinking and moving to the edges as a new statistic is shown. Some statistics shown in this visualisation are the risks of children being harmed in the U.S. compared to other countries. The final visualisation is similar in design to the previous one. However, this visualisation is anchored around one use of guns in self-defence. Comparing how often guns are used in self-defence with other gun related crimes.

Visualisation 2

This visualisation is focused on comparing statistics in the United States regarding gun control with other countries that are generally deemed to be dangerous or war torn. To depict these differences a simplified image of the U.S. is used as a small figure of a person tours the country At each state the man visits a new statistic is revealed comparing homicides in these states and other countries (Figure 27).

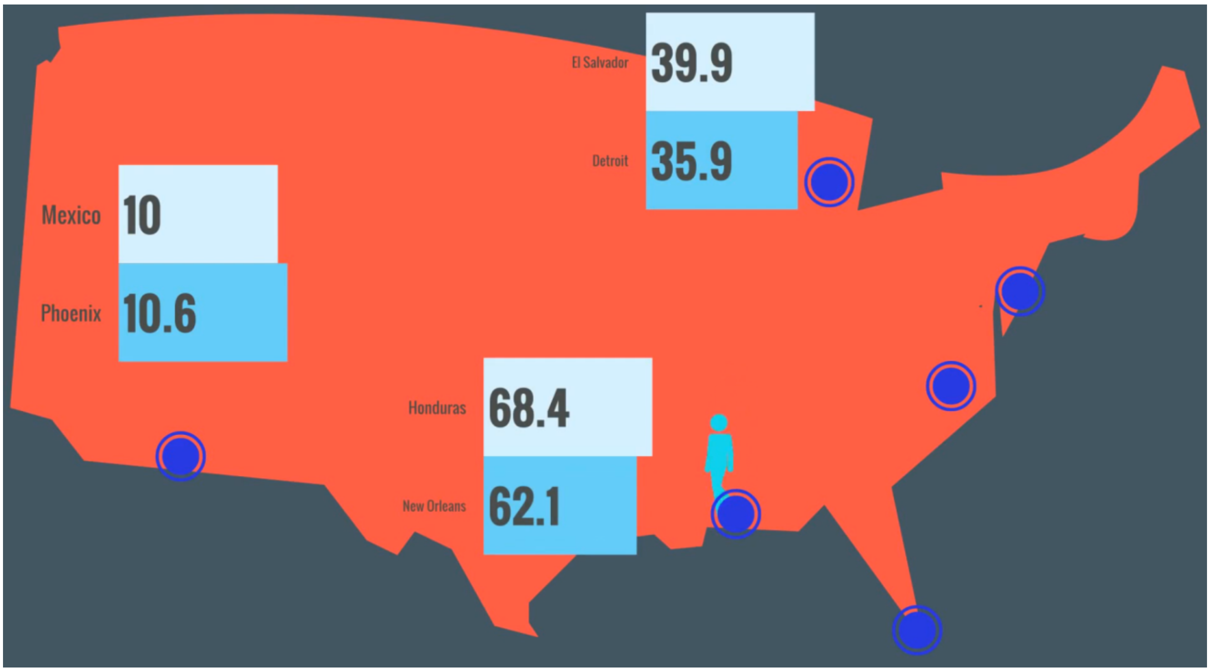

Figure 27 Visualisation of homicide rates in other countries compared to states within the U.S.

Visualisation 3

This visualisation was intended to discuss a possible alternative to gun control being connected to gun related crime. In particular, this visualisation discusses poverty and uses symbolism to compare wealth and gun violence. An example of the symbolism used is a small house compared to a large one. This was used to represent poorer residents compared to the wealthy.

Figure 28 Visualisation comparing poorer residents with wealthier residents in regards to gun crime.

Visualisation 4

This visualisation was designed to be similar to the visualisation that showed statistics rapidly. However, this one focuses its visualisations around the state of Louisiana.

Figure 29 Louisiana visualisation showing multiple statistics related to that state.

Visualisation 5

This visualisation focuses on the connections between gun control, specifically gun permit requirements, and burglary rates. To represent the difference between the two states a 10 by 10 grid of stick figure men were used. As the colour is changed it is revealed that every stick figure that changes colour is a percentage decrease in the burglary rate. This visualisation was specifically designed to represent how many cases of criminal burglary could be avoided with stricter gun laws.

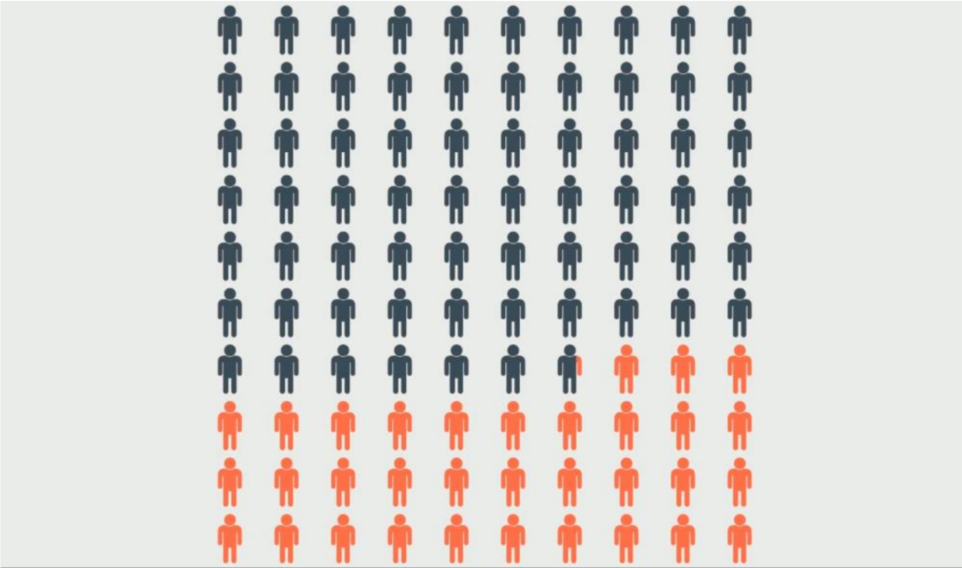

Figure 30 Burglary rates without gun control (all stick figures) compared to with gun control (only blue stick figures).

Visualisation 6

The final visualisation is the suicide statistics visualisation discussed in Chapter 3 as an example of implementing the narrative visualisation techniques developed in this dissertation. This visualisation is focused on comparing the success rate of suicide attempts when guns are used compared to other methods. To represent a human life a heart rate monitor is used, with the heart rate flatlining being used to represent the death of the person (Figure 12 & 13).

Chapter 5 – Results

Following the conclusion of the user study, the questionnaire responses and readings from the Unity program were taken and analysed to evaluate the effectiveness of the visualisations and to decide if the use of virtual reality had an impact on the experience. This study takes into account both qualitative and quantitative results as well as ad hoc discussion with the participants and notes from the questionnaire. The Unity readings are all recorded in seconds except for total clicks which is measured per primary click. The primary click is considered as the left mouse button for desktop and the trigger on the Vive controller for VR as they achieve the same affect. The questionnaire is graded on a Likert Scale from 1 – 5. The study resulted in two different sets of results for each user, the raw data output from Unity and the questionnaire results.

Chapter 5.1 – Quantitative Results

The raw output included a variety of recorded statistics including total time, the number of clicks, time spent using the laser pointer, and time spent within each visualisation. As this study was conducted on two groups of participants whom only completed one version of the program an independent t-test was run. From this test, mean, standard deviation, standard error, significance, degrees of freedom, and effect size were calculated using SPSS statistics for each variable. For each variable Levene's Test was run to assess equality of variance. The variables of particular focus for this study were number of clicks, total time. and the time spent using the laser. These variables most closely record the behaviour of the participants in the study and are therefore used to measure differences in behaviour between desktop users and those who used the HTC Vive headset.

For total time, participants in virtual reality spent longer in the experiment ($M = 590$, $SE = 58.6$) than those in desktop ($M = 555$, $SE = 42.8$). This difference, 35 seconds, was not significant however $t(28) = -0.47$, $p = 0.32$; it also showed a minimal effect size, $d = 0.09$. Similarly, the number of clicks for VR ($M = 12.9$, $SE = 2.7$) compared to desktop ($M = 10.5$, $SE = 0.98$) showed minimal difference, 2.4 clicks. This difference was not significant, $t(28) = -0.85$, $p = 0.2$ and showed a minimal effect size, $d = 0.18$. For time spent using the laser pointer, VR ($M = 102.3$, $SE = 18$) compared with desktop ($M = 172.08$, $SE = 26.1$), with a difference of 69.78 actually showed desktop having a higher mean. However this difference is significant, $t(28) =$

2.2, p = 0.02; and showed a medium-sized effect, d = 0.38. Full results can be seen in Table 1 and Table 2.

These results suggest minimal difference in behaviour for users in both VR and desktop. The only major difference that is significant is that desktop users tended to use the laser pointer for longer than those in VR (see Discussion).

	Group	Mean	Std. Deviation	Std. Error Mean
Num. of Clicks	Desktop	10.53	3.796	0.98
	VR	12.93	10.32	2.67
Time in All Vis	Desktop	360.1	101.64	26.24
	VR	379.18	136.94	35.35
Time in States	Desktop	119.7	73.15	18.89
	VR	112.99	70.13	18.74
Time in Laser	Desktop	172	101.34	26.16
	VR	102.32	69.75	18
Total Time	Desktop	555.19	169.75	43.75
	VR	589.88	227.02	58.6

Table 1 Results for independent t-test regarding user behaviour

Comparing time spent looking at the six visualisations (see Table 3) only one of the visualisations has a difference of means that is considered significant, $p < 0.05$. Participants spent longer looking at the sixth visualisation in VR (M = 79.75, SE = 12.14) than in desktop (M = 46.73, SE = 4.74). This difference of the means, 33.02, is significant with $t(26) = -2.53$, $p = 0.01$; and showed a large effect size, d = 0.52. This result is counterintuitive as it can be fairly assumed that any behaviours exhibited on one visualisation would be similar for others. The result of Levene's test for equality of variance seems to confirm this suspicion $F(16.9, 26) = 11.4$, $p = 0.002$; therefore failing the Levene's test. A possible cause to this discrepancy of behaviour may be found in the ad hoc discussions with the participants in the study. Multiple participants of the VR study reported audio issues on this visualisation that made it appear as if it has crashed. As such, many users reported watching the visualisation again to see the end of it. This issue with the project could account for the extended time spent in this visualisation and its significant difference of means. This outlier case also confirms another trend found in the results (see Discussion).

	Group	Mean	Std. Deviation	Std. Error Mean
Time In Vis 1	Desktop	70.98	36.4	9.39
	VR	65	19.87	5.31
Time In Vis 2	Desktop	49.59	26.9	6.94
	VR	53.41	29.17	6.99
Time In Vis 3	Desktop	73.5	29.18	7.8
	VR	74.8	16.49	4.57
Time In Vis 4	Desktop	43.46	20.95	5.6
	VR	52.97	44.6	11.51
Time In Vis 5	Desktop	86.62	25.19	6.5
	VR	83.18	9.74	2.7
Time In Vis 6	Desktop	46.73	17.75	4.74
	VR	79.75	45.43	12.14

Table 2 Results for independent t-test regarding visualisation viewing

Chapter 5.2 – Qualitative Results

The second half of the results revolves around the questionnaire (see User Questionnaire in Appendix A – User Study Resources). As previously mentioned the questionnaire was split into two sections. The first were a set of 5 questions designed to gauge whether the user felt the experience was improved by the specific technology they used. These questions are labelled as ‘Vis’ questions in Table 3 and were:

Vis Q1: You felt that the medium you used (Desktop or VR) added to the overall experience?

Vis Q2: You found the use of audio increased the overall experience?

Vis Q3: You felt the message of the program was clear?

Vis Q4: You felt that the information was displayed honestly and without bias?

Vis Q5: You found the program convincing or thought provoking?

The second set of questions were designed to gauge the levels of presence experienced by the users throughout the visualisations. These questions were based on the subset of the B. Witmer and M. Singer questionnaire offered in their paper "Measuring Presence in Virtual Environments" [9], discussed in M. Slaters paper "Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire" [43]. These questions are labelled as "Pres" questions in Table 3 and were:

Pres Q1: How much were you able to control events?

Pres Q2: How responsive was the environment to actions that you initiated (or performed)?

Pres Q3: How well could you move or manipulate objects in the virtual environment?

Pres Q4: How much did the visual aspects of the environment involve you?

Pres Q5: How compelling was your sense of moving around the virtual environment?

Pres Q6: How well could you examine objects from multiple viewpoints?

Pres Q7: How aware were you of events occurring in the real world around you?

Pres Q8: How aware were you of your display and control devices?

Pres Q9: How distracting was the control scheme?

Pres Q10: How inconsistent or disconnected was the information coming from your various senses?

Pres Q11: To what degree did you feel confused or disorientated at the beginning of breaks or at the end of the experimental session?

Pres Q12: How much did your experience in the virtual environment seem consistent with your real-world experience?

Each questionnaire was marked on a Likert Scale of 1 – 5 with the anchors of "Strongly Disagree – Not Sure – Strongly Agree". These results went through a nonparametric test, specifically the Mann-Whitney U test. As such for each question the mean, median, Mann-Whitney U score, z – score, significance, and effect size were calculated. These results can be viewed in full in Table 3 and Table 4.

Out of the 15 questions asked only three returned a significant result. Those three questions are Q1, Q2 and Q7:

Vis Q1: *You felt that the medium you used (Desktop or VR) added to the overall experience?*

Vis Q2: *You found the use of audio increased the overall experience?*

Pres Q7: *How aware were you of events occurring in the real world around you?*

Question	Median	Mann Witney U	Z Score	Significance	Effect Size
Vis Q1	4	54.5	-2.65	0.004	-0.48
Vis Q2	4	74.5	-1.8	0.034	-0.33
Vis Q3	5	88.5	-1.2	0.1065	-0.23
Vis Q4	4	93	-0.88	0.191	-0.16
Vis Q5	4	105.5	-0.33	0.3725	-0.06
Pres Q1	4	109.5	-0.15	0.441	-0.03
Pres Q2	4	101	-0.57	0.2835	-0.10
Pres Q3	4	79.5	-1.48	0.07	-0.27
Pres Q4	4	105	-0.34	0.369	-0.06
Pres Q5	4	96	-0.71	0.2405	-0.13
Pres Q6	3.5	81.5	-1.34	0.0895	-0.25
Pres Q7	3	70.5	-1.82	0.0345	-0.33
Pres Q8	4	107.5	-0.22	0.4115	-0.04
Pres Q9	2	93	-0.84	0.2005	-0.15
Pres Q10	3	92.5	-0.89	0.187	-0.16
Pres Q11	2	108.5	-0.18	0.429	-0.03
Pres Q12	3	90	-1.04	0.149	-0.19

Table 3 Results for each question in questionnaire

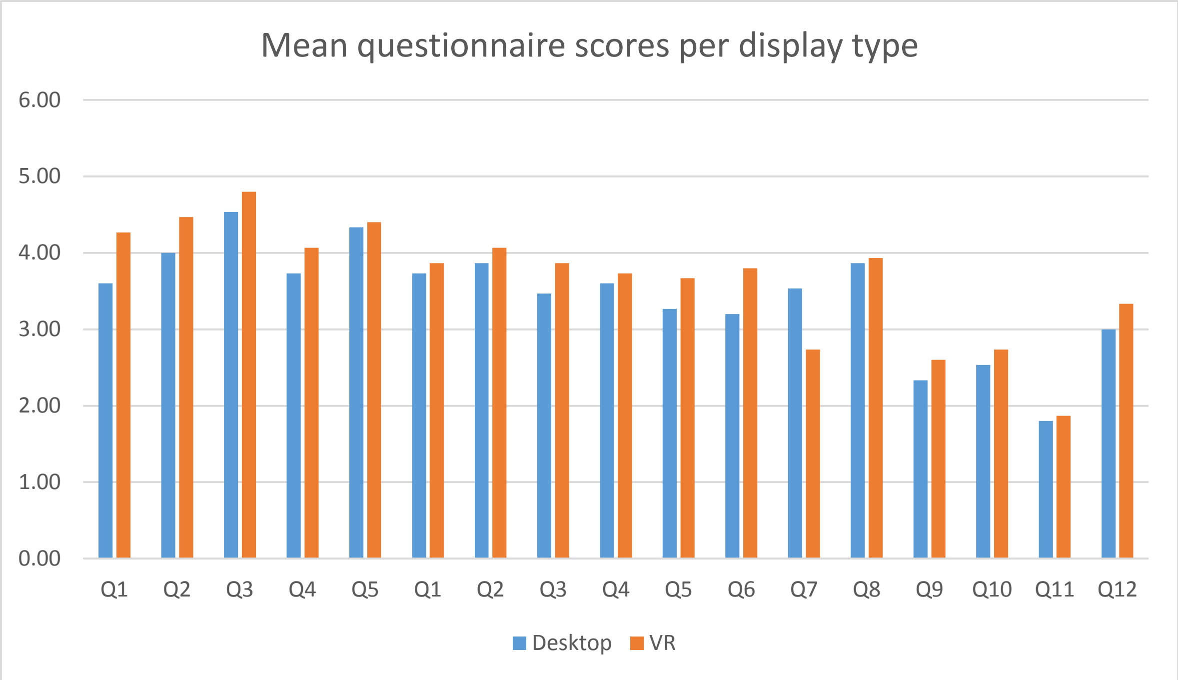

Table 4 Means for questions in desktop and VR

For the Vis Q1, users in VR answered more positively than those who used a desktop display, U = 54.5, z = -2.65, p = 0.004 and displayed a medium-sized effect, r = -0.48. Vis Q2 had a similar result with U = 74.5, z = -2.65, p = 0.034, and r = -0.33. Finally question seven had U = 70.5, z = -1.82, p = 0.0345 and a medium effect size of r = -0.33. Pres Q7, as observable when comparing means (Table 4), shows a more positive result for desktop compared to VR. However, Pres Q7 is a negatively worded question, with a higher result suggesting a lower level of presence as the user is more aware of the world around them. As such a positive result for desktop should be considered as a possibly increased sense of presence within the VR experience.

Chapter 6 – Discussion

In this section the user and study and its results will be discussed. This chapter will begin with an analysis of the ad hoc discussions and criticisms from participants as well as some considerations written by participants in the survey. These criticisms will be considered in respect to observations found through user behaviour throughout the study and possible solutions will be recommended. Finally, this chapter will conclude with possible future expansions on this study will be suggested.

Chapter 6.1 – Results Discussion

From these results, it can be concluded that regardless of the medium used for narrative visualisations the actions and behaviour of the participants is not significantly different. Users appeared to spend a similar amount of time within the virtual world for both sets of technology as can be seen by a lack of significant difference in total run times for both desktop and VR. Similarly, very little distinction in interaction with the environment for either medium, with opposite results to what was expected with desktop users spending more time using the laser. Time spent looking at each visualisation returned no significant difference which reflects what was expected. Comparing the means for each visualisation with the run time of the attached data video show very similar durations. From this comparison, it can be inferred that most users watch each visualisation once, with slight variations most likely arising from users reselecting a visualisation to add it to the favourites board. The questionnaires returned results more in line with expectations with users who participated in the VR experience recording that the medium of VR did in fact enhance the experience, as did the inclusion of audio components. It is worth noting that the addition of audio components returned a more positive result in VR further adding to the conjecture that audio is a key component in immersive VR experiences. The more positive results towards awareness of surroundings while using the desktop display further add to the possible immersive qualities of VR. However, other questions, aimed to measure presence failed to reveal a significant difference in VR compared to desktop. These results are counter intuitive and go against prevailing research.

Chapter 6.2 – Participant Discussion

The final section of the questionnaire allowed the participant to write down any thoughts or constructive considerations of their experience. This section discusses some of these thoughts and discovers trends.

Chapter 6.2.1 – Interaction and Navigation

In an attempt to create two experiences that were as similar as possible the desktop prototypes major form of interaction and selected was through a laser pointer. This mechanic mirrors the laser pointer that is used within the VR experience. One user who experienced the desktop visualisations found this use of a laser to be counter intuitive as the mouse cursor could have been used for to a similar affect. This problem could be solved by a redesign of the desktop application to take advantage of the unique control scheme allowed by a mouse and keyboard.

When activated, some of the “Area Spheres” visualisations would be played from different sections of the environment. This was done to emphasise the freedom of movement and space allowed by a virtual environment. However, one visualisation was placed behind the starting field of view of the VR participants. This led to confusion as users were not expecting to have to move their head to see a visualisation. This complaint was mirrored by many of the VR participants. While it could be argued that this issue rises from a lack of experience of the capabilities of VR, the issue could also be resolved with visual cues to show the user where in the virtual space the currently selected visualisation is located.

One observation from the study was that both within VR and desktop the participants failed to track the metaphor of the spheres compared to the actual visualisation. In the instructions, it stated that by aiming the laser at the visualisation it would be added to favourites however many of the participants instead tried to aim the laser at the sphere itself. Other users struggled to use the Vive controllers and show particular difficulty in using the laser and trigger at the same time. Users of the VR prototype found it difficult to understand how moving the controller into the “Area Sphere” worked and in general were prone to standing still. Most of these issues arose in VR and users generally had minimal difficulties navigating and interacting in desktop. A solution to these problems is the introduction of a tutorial or instructional “test-run” of the study. This would allow the users to get experience in VR and the controllers and how interactions in the world work.

Chapter 6.2.2 – Visualisations

Ad hoc remarks from the users suggested that most enjoyed or found interest within the narrative visualisation data videos. Interestingly some users actually found the one data visualisation, an interact able map of the United States of America, to be the most engaging as it allowed them to discover trends or interesting facts independently. Of the narrative visualisations one user claimed that the suicide statistic visualisation was the most impactful as they felt an emotional response to the data. Multiple users suggested removing the text-to-speech voice and replacing it with a real human voice actor. The users also felt that matching the music to be more closely correlated with the visualisations could have been used to build tension and strengthen the narrative of some of the visualisations.

A majority of the users forgot to favourite visualisations at all. This trend was noticed in both desktop and VR environments, and suggests that users were not clear on the goal of the task. This problem could be avoided through a short introduction where a narrator could inform the user to favourite visualisations for comparison at the end.

Chapter 6.2.3 – Summary

Due to the lack of time available a pilot study was ignored and as such some simple issues that could have been resolved may have had a negative impact on the experience. Given a second study the following improvements would have been made:

- The introduction of a tutorial section. This section would allow the user to get comfortable using the controls.
- In addition to a tutorial an introduction that describes to each participant the reason that they are in the virtual world and what the clear goal is of the project.
- The inclusion of more complex visualisations that allow for interaction. Included on this improvement could be a version of each visualisation in which narrative techniques have been removed to allow the user a representation of the data that avoids bias.
- Increasing the study size and using a more varied demographics of users would allow for a more balanced and significant review of the techniques and technology.

The lack of noticeable presence recorded through the questionnaire suggests improvements to the VR experience should be made. Despite this lack of presence, the VR experience received higher praise than the desktop equivalent and users were interested and attentive to the narrative visualisations on display.

In concluding the results, it can be said that the research question "*Is a narrative visualisation enhanced by the inclusion of Virtual Reality technology?"* is not successfully answered by this user study.

Chapter 7 – Conclusion

This dissertation presents contributions to multiple research fields. In regards to visualisations and big data analysis this paper contributes a set of design techniques and steps to create visualisations with storytelling properties for the intended goal of generating an emotional response or expressing an opinion. For the research area of virtual reality this dissertation contributes designs for implementing narrative visualisations in an explore able and interactive 3D environment. As a result of the user study and following analysis of its results to test the advantages of virtual reality in conjunction with narrative visualisations, the visualisations are presented as being successful while the advantages of the virtual environment is inconclusive.

In this chapter, justification for the contributions offered by this dissertation will be made through the results found in the user study and from discussions with the participants. Finally, this chapter is concluded with some final remarks.

Chapter 7.1 – Research Questions and Contributions

This dissertation originally proposed two research questions:

Q1: Is a narrative visualisation enhanced by the inclusion of Virtual Reality technology?

Q2: What are a set of suitable techniques to develop narrative visualisations in virtual space?

From the results of the user study performed it can be concluded that no significant result could be recorded to substantiate the claims of the first research question. However, a few significant results suggest a possible correlation between a more positively viewed experience by the user and the virtual reality medium offered. These results suggest further research is worth conducting to more thoroughly discuss the answer to this research question.

Discussions and closing remarks from participants who viewed the visualisations suggest that the inclusion of narrative visualisation into a 3D explore able virtual space, and the techniques that were designed to create them, were impactful and more engaging than other techniques.

As well as answering these research questions this paper offers a set of contributions. The first contribution was a set of techniques for taking statistics gathered via data analytics and converting them into a narrative visualisation. These narrative visualisations are focused on engaging with the viewer and highlighting trends.

The second contribution was a strategy for placing the narrative visualisations created into a 3D virtual space that a user can explore and interact with at will. The virtual space developed was designed with an abstract theme to allow the visualisations to be the focal points of the experience. A modular approach was taken to incorporating the visualisations into the environment.

The final contribution was a user study designed to compare the advantages of showing these designs through virtual reality compared to a standard desktop display. Results were inconclusive but showed promising trends towards the strength of narrative visualisations compared to standard visualisation techniques and also suggested an improvement of the overall experience when using virtual reality technology.

Chapter 7.2 – Future Work

The techniques presented in this dissertation provide a complete set of techniques for deriving narrative visualisations from big data analysis. The dissertation also provides techniques for including these visualisations into a 3D virtual space. However, as the results of the study were inconclusive and only suggested an improved experience in virtual reality, future improvements and research remain. This section discusses some potential areas for future work and expansions on this dissertation contributions.

Chapter 7.2.1 – Visualisations

The techniques described earlier in this dissertation for constructing narrative visualisations focused primarily on data that had already been analysed and summarised. However, this is an unrealistic assumption and narrative visualisation can begin to form as early as the analysis stage of data visualisation. As such more research could be done into how to spot narratives and track trends in data at this early stage could be done. Similarly, the narrative visualisations designed throughout this paper are primarily data videos. Incorporating storytelling elements into visualisations lends itself naturally to data videos. Data videos however, lack interaction and as such are limited to linear visualisations. Exploratory visualisations are an area for future research with possibilities to allow viewers to drill down and explore more in-depth data relevant to the topic of the visualisation. One area of improvement is in the incorporation of modular narrative design elements. All of the narrative visualisations designed for this dissertation are hard coded and created specifically for the data available. The development of a more adaptive and modular design methodology for narrative visualisations could prove to allow for more powerful visualisations to be designed rapidly.

Chapter 7.2.2 – Virtual Reality

The HTC Vive is a powerful system that is easily incorporated into current game engine development environments. As such, this paper only scratches the surface of the potential complexity of visualisation environmental design.

Multiple participants suggested incorporating a larger area to explore. The area was kept small to avoid difficulties inherent in VR navigation and to accommodate the comparatively small set of visualisations available. Future research could include incorporating more complex visualisations and placing them inside a more varied and complex virtual environment. Implementing this concept would require research into navigation in virtual environments due to the limited walking area allowed by HTC Vive. Another consideration for future work is the implementation of a live communication system between the author and the user. Taking the structure used in role playing games (RPG) like Dungeons and Dragons could allow for the live customisation of the environment and visualisations available as a reaction to user behaviour.

Chapter 7.3 – Concluding Remarks

Big data continues to put pressure on data scientists to find new and engaging ways of representing datasets to appeal to wider demographics of users. Narrative visualisation is a promising new field that incorporates tried and tested techniques applied to other narrative fields to widen the scope of visualisation possibilities. Simultaneously, the field of VR research, with measured increases in presence and immersion for users, remains a promising new realm of possibilities for visualisation techniques.

The proposed visualisation techniques in conjunction with VR technology shows promise despite not returning conclusive results. It is believed that future iterations of these techniques and a more thorough user study will find significant advantages to the combinations of these varying fields of research.

Chapter 8 – References

[1] F. P. Brooks, "What's real about virtual reality?," *IEEE Computer Graphics and Applications,* vol. 19, pp. 16-27, 1999.

[2] P. Milgram, H. Takemura, A.Utsumi, and F. Kishino, "Augmented Realty: a class of displays on the reality-virtuality continuum.," *Proceedings of Society of Photographic Intrumentation Engineers,* pp. 282-292, 1995.

[3] E. Segel and J. Heer, "Narrative Visualisation: Telling Stories with Data," *IEEE Transactions on Visualisation and Computer Graphics,* vol. 16, 2010.

[4] G. Lopez. (2015). *More guns mean more gun murders. Here's how we know.* Available: http://www.vox.com/policy-and-politics/2015/12/8/9870240/gun-ownership-deaths-homicides

[5] (2014). *Comparing Murder Rates and Gun Ownership Across Countries*. Available: http://crimeresearch.org/2014/03/comparing-murder-rates-across-countries/

[6] C. Woodruff. (2015). *If You Live In Louisiana You're Nearly Twice as Likely to Be Killed By a Gun*. Available: https://www.thetrace.org/2015/07/louisiana-gun-violence-shooting-movie-theater/

[7] M. V. Sanchez-Vives and M. Slater, "From presence to consciousness through virtual reality," vol. 6, April 2015.

[8] M. Slater, A. Frisoli, F. Tecchia, C. Guger, B. Lotto, A. Steed*, et al.*, "Understanding and Realizing Presence in the Presenccia Project," *IEEE Computer Graphics and Applications,* vol. 27, pp. 90-93, 2007.

[9] B. G. Witmer, M. F. Singer, A. R. I. F. T. BEHAVIORAL, and S. S. A. VA, "Measuring Presence in Virtual Environments," 1994.

[10] F. Amini, N. H. Riche, B. Lee, C. Hurter, and P. Irani, "Understanding Data Videos: Looking at Narrative Visualisation through the Cinematography Lens," 2016.

[11] E. Olshannikova, A. Ometov, Y. Koucheryavy, and T. Olsson, "Visualizing Big Data with augmented and virtual reality: challenges and research agenda," *Journal of Big Data,* vol. 2, pp. 1-27, 2015.

[12] "Visualizations Make Big Data Meaningful," *Communications of the ACM,* vol. 57, pp. 19-21, 2014.

[13] A. Ritu and D. Vasant, " Editorial—Big Data, Data Science, and Analytics: The Opportunity and Challenge for IS

Research," *Information Systems Research,* vol. 25, pp. 443-448, Sep 2014.

[14] M. Hohl, "From abstract to actual: art and designer-like enquiries into data visualisation," *Kybernetes,* vol. 40, pp. 1038-1044, 2011

2011-09-15 2011.

[15] B. Hentshel, M. Wolter, and T. Kuhlen, "Virtual Reality-Based Multi-View Visualisation of Time-Dependent Simulation Data," presented at the IEEE Virtual Reality Conference, Lafayette, LA, 2009.

[16] C. Donalek, S. G. Djorgovski, A. Cioc, A. Wang, J. Zhang, E. Lawler*, et al.*, "Immersive and collaborative data visualization using virtual reality platforms," presented at the IEEE International Conference on Big Data, Washington, DC, 2014.

[17] R. A. Layton, R. A. House, M. W. Ohland, and G. Ricco, "Promoting more effective communication of stories in the data," in *Frontiers in Education Conference (FIE), 2014 IEEE*, 2014, pp. 1-4.

[18] C. Chapman. (2009). *50 Great Examples of Data Visualisation*. Available: http://www.webdesignerdepot.com/2009/06/50-great-examples-of-data-visualization/
[19] M. Dittrich. (2016). *Narratives 2.0*. Available: http://www.matthiasdittrich.com/projekte/narratives/visualisation/index.html
[20] K. Anand. (2008). *Looks Del.icio.us*. Available: http://kunalanand.com/delicious/
[21] K. Boyack, D. Klavans, and W. B. Paley. (2006). *The Strengths of Nations*. Available: http://wbpaley.com/brad/mapOfScience/index.html
[22] LeisureArts. (2005). *Is The New*. Available: http://thediagram.com/6_3/leisurearts.html
[23] Bumblebee. (2008). *1hr in front of the TV*. Available: http://tinyurl.com/55tlpz
[24] S. Kamvar. (2006). *We Feel Fine*. Available: http://number27.org/wefeelfine
[25] D. Bowker. (2008). *One week of The Guardian*. Available: http://tinyurl.com/6lgezl
[26] J. Haggerty, S. Haggerty, and M. Taylor, "Forensic triage of email network narratives through visualisation," *Information Management & Computer Security,* vol. 22, p. 358, 2014

2015-06-20 2014.
[27] A. Cockburn, A. Karlson, and B. Bederson, "A review of overview+detail, zooming, and focus+context interfaces," *ACM Computing Surveys,* vol. 41, 2008.
[28] M. Waldner, M. L. Muzic, M. Bernhard, W. Purgathofer, and I. Viola, "Attractive Flicker Guiding Attention in Dynamic Narrative Visualisations," *IEEE Transactions on Visualisation and Computer Graphics,* vol. 20, pp. 2456-2465, 2014.
[29] M. L. Huang, T.-H. Huang, and X. Zhang, "A novel virtual node approach for interactive visual analytics of big datasets in parallel coordinates," *Future Generations Computer Systems,* vol. 55, pp. 510-523, 2016.
[30] J. S. Yi, Y. a. Kang, and J. Stasko, "Toward a Deeper Understanding of the Role of Interaction in Information Visualization," *IEEE Transactions on Visualization and Computer Graphics,* vol. 13, pp. 1224-1231, 2007.
[31] J. Hullman and N. Diakopoulos, "Visualization Rhetoric: Framing Effects in Narrative Visualization," *IEEE Transactions on Visualization & Computer Graphics,* vol. 17, pp. 2231-2240, 2011.
[32] J. Hullman, S. Drucker, N. H. Riche, B. Lee, D. Fisher, and E. Adar, "A Deeper Understanding of Sequence in Narrative Visualization," *IEEE Transactions on Visualisation and Computer Graphics,* vol. 19, December 2013 2013.
[33] P. Jacobs, S. Kane, C. Jones, M. Farry, and J. Niehaus, "Towards Visualizations to Support the Construction of Narratives for Analysis," ed: Elsevier B.V., 2015.
[34] A. Figueiras, "Narrative Visualisation: A Case Study of How to Incorporate Narrative Elements in Existing Visualisations," presented at the 2014 18th International Conference on Information Visualisation, 2014.
[35] N. Cohn, "Visual Narrative Structure," *Cognitive Science,* vol. 34, pp. 413-452, 2013.
[36] S. Maria RoussouMartin OliverMel, "The virtual playground: an educational virtual reality environment for evaluating interactivity and conceptual learning," *Virtual Reality,* vol. 10, pp. 227-240, Dec 2006

2014-08-30 2006.
[37] Z. Sun, A. Dhital, N. Areejitkasem, N. Pradhan, and A. Banic, "Effects on Performance of Analytical Tools for Visually Demanding Tasks through Direct and Indirect Touch Interaction in an Immersive Visualization," in *Virtual Reality and Visualization (ICVRV), 2014 International Conference on*, 2014, pp. 186-193.

[38] N. d. l. Pe, P. Weil, J. Llobera, B. Spanlang, D. Friedman, M. V. Sanchez-Vives*, et al.*, "Immersive Journalism: Immersive Virtual Reality for the First-Person Experience of News," *Presence,* vol. 19, pp. 291-301, 2010.
[39] A. Rizzo, A. Hartholt, M. Grimani, A. Leeds, and M. Liewer, "Virtual Reality Exposure Therapy for Combat-Related Posttraumatic Stress Disorder," *Computer,* vol. 47, pp. 31-37, 2014.
[40] H. R. Nagel and E. Granum, "Explorative and dynamic visualization of data in virtual reality," *Computational Statistics,* vol. 19, pp. 55-73, Feb 2004

2014-08-30 2004.
[41] C. Helbig, H.-S. Bauer, K. Rink, V. Wulfmeyer, and M. F. O. Kolditz, "Concept and workflow for 3D visualization of atmospheric data in a virtual reality environment for analytical approaches.," *Environmental Earth Sciences,* vol. 72, pp. 3767-3780, 2014.
[42] S. Sanji, M. Murata, P.Hartono, and S. Hashimoto, "A Virtual Reality System For High-Dimentional Data Visualisation," presented at the IEEE International Conference on Multimedia and Expo, Tokyo, Japan, 2001.
[43] M. Slater, "Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire," *Presence,* vol. 8, pp. 560-565, 1999.
[44] D. Matthews. (2015). *11 Facts About Gun Violence in the United States*. Available: http://www.vox.com/cards/gun-violence-facts
[45] Wikipedia. (2016). *Gun Violence in the United States by state*. Available: https://en.wikipedia.org/wiki/Gun_violence_in_the_United_States_by_state

Appendix A – User Study Resources

This section provides all the resources that were used when conducting the user study.

Participant Consent Form

UniSA | Research and Innovation Services

Human Research Ethics Committee
CONSENT FORM

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of this Committee, Tel: +61 8 8302 3118; Email: Vicki.Allen@unisa.edu.au

SECTION 1: CONTACT AND PROJECT DETAILS

Researcher's Full Name:	Jim Bastiras
Contact Details:	Email: basjb001@mymail.unisa.edu.au Phone: 0468 398 922
Supervisor's Full Name:	Professor Bruce Thomas
Contact Details:	Email: bruce.thomas@unisa.edu.au Phone: 8302 3464
Protocol Number:	TBA
Project Title:	Using Virtual Reality and Narrative Visualisation Techniques to Persuade a User

SECTION 2: CERTIFICATION

Participant Certification

In signing this form, I confirm that:

- I have read the participant information sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential. No information, which could lead to the identification of any individual, will be released, unless required by law.
- I understand that my anonymous results may be used for future research, subject to further ethics approval.
- If further information relating to my participation in the present study is required, I give permission for the researchers to contact me.

Participant Signature	*Printed Name*	*Date*

Researcher Certification

I have explained the study to subject and consider that he/she understands what is involved.

Researcher Signature	*Printed Name*	*Date*

User Questionnaire

1. You felt that the medium you used (Desktop or VR) added to the overall experience?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

2. You found the use of audio increased the overall experience.

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

3. You felt that the message of the program was clear.

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

4. You felt that the information was displayed honestly and without bias.

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

5. You found the program convincing or thought provoking.

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

1. How much were you able to control events?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

2. How responsive was the environment to actions that you initiated (or performed)?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

3. How well could you move or manipulate objects in the virtual environment?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

4. How much did the visual aspects of the environment involve you?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

5. How compelling was your sense of moving around the virtual environment?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

6. How well could you examine objects from multiple viewpoints?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

7. How aware were you of events occurring in the real world around you?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

8. How aware were you of your display and control devices?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

9. How distracting was the control mechanism?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

10. How inconsistent or disconnected was the information coming from your various senses?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

11. To what degree did you feel confused or disorientated at the beginning of breaks or at the end of the experimental session?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

12. How much did your experience in the virtual environment seem consistent with your real world experience?

Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree

If you have any thoughts please feel free to write them out below. Thank you for participating!

Participant Information Sheet

University of South Australia

School of Information Technology and Mathematical Sciences

Division of Information Technology, Engineering and the Environment

Using Virtual Reality and Narrative Visualisation Techniques to Persuade a User.

Researcher: Mr Jim Bastiras Supervisor: Prof. Bruce Thomas
0468 398 922 8302 3464
basjb001@mymail.unisa.edu.au bruce.thomas@unisa.edu.au

The HTC Vive is a Virtual Reality system that integrates head and controller tracking software within a 5 metre by 5 metre room to allow the user to look and move around a completely virtual environment. With some of the most advanced technology behind it the Vive allows the most realistic sensation of actually being in a virtual world. This research aims to show that using this technology enhances the effectiveness and experience of narrative visualisation; the technique for telling stories with data.

The study will take place in one 15-minute session at the E-World Lab on the Mawson Lakes campus of the University of South Australia. Participants must be between the ages of 18 and 40, normal or correctly to normal vision.

You will be required to answer several screening questions either online or over the phone with the researcher. These questions are related to your general physical and mental health, as well as basic demographic information, and will determine your eligibility to participate. If you are eligible to participate you will be asked to attend the laboratory for a 15-minute session at a time that is convenient for you. During the session you will participate in a Virtual Reality Experience. During the main task, you will be instructed on how to interact with the virtual world before being allowed to freely explore a set of visualisations that aim to inform you of some statistics regarding the issue of gun control in the United States.

Participation is strictly on voluntary basis. You are free to withdraw from the research project at any stage without affecting your status, now or in the future. You will be compensated with a small chocolate gift as a thank you for your time.

In accordance with the Australian Code for the Responsible Conduct of Research, all information collected as part of this study will be retained for five years in a safe environment. Electronic data will be encrypted and stored in the System Administrators office in the School of Information Technology and Mathematical Sciences, University of South Australia. Paper based data will be stored in a locked filing cabinet in the School of Information Technology and Mathematical Sciences. All records containing personal information will remain confidential, and no information which could lead to the identification of any individual will be released, unless required by law. The researcher will take every care to remove responses from any identifying material as early as possible. Likewise, individual responses will be kept confidential by the researcher and not be identified in the reporting of the research. However, the researcher cannot guarantee the confidentiality or anonymity of material transferred by email or internet. Summarised results may be used in theses, and journal and conference publications. In addition, anonymous, task-performance results may be used for other future and relevant research conducted by the Wearable Computer Lab, for which ethics approval will be sought. As a participant in this study, you will be given the opportunity to receive a copy of any publication made that has reference to the results obtained.

This project has been approved by the University of South Australia's Human Research Ethics Committee.

The Executive Officer HREC is available to discuss any ethical concerns you may have about this user study. Her contact details are included below.

Vicki Allen
Executive Officer
Human Research Ethics Committee, University of South Australia
Research Services, Mawson Lakes Campus
Email: vicki.allen@unisa.edu.au
Phone: 8302 3118
Fax: 8302 3921