3D Data Visualization in Virtual Reality: Getting to Today

Abstract

In the era of Big Data, we are generating an exponentially increasingly large volume of data and with it, an increased demand for meaningful insights to better understand the world. The amount and detail of the data along with improvements in analysis technology yields increasingly complex, interconnected results. Ultimately, these results need to be communicated in order to create actionable plans to harness this new information. Indeed, more powerful and complex tools are being created in order to facilitate this need for communication. 3Data is a software company that has built a such a tool: a cutting-edge data visualization platform. 3Data’s immersive virtual reality (VR) environment allows users to explore scaffolded, animated, interactive, 3D data in various, rich formats. But are more powerful tools of representing information always more useful? This paper looks to the available literature to review if, and how, more complex representations of data can, in fact, improve learning outcomes. It finds that such full-featured data visualization platforms can promote improved learning outcomes provided that each feature is included for a specific purpose and is utilized appropriately.

Introduction

One of the most amazing human traits is the ability to learn without direct experience through the communication of abstract concepts. Humans have developed mechanisms to convey information and meaning such as language and art. Tversky (2011) points out how it was only recently that artifacts such as cave paintings and bone cuttings have been studied outside of the domain of art, yet these were tools to convey meaning created thousands of years before the invention of written language. Now, these historic mechanisms are being studied along with computers and visual instructions to understand how they are understood by the mind. Scientists are currently attempting to systematically understand and improve the ability to communicate complex, abstract ideas in a visual manner.

In his seminal book “The Visual Display of Quantitative Information” (1983), Edward Tufte explores the history, triumphs, and failures of graphical representation of data. Tufte defines a practical theory and language with which to discuss data graphic which is still widely used and cited today. He suggests six fundamental principles of design: show comparisons, show causality, use multivariate data, integrate modes (such as text and images), establish credibility, and focus on content (Tufte, 1983).
While Tufte outlines the importance of simplicity and building up to meaning, Tversky recognizes that any representation is an act of subtraction. “Because assigning meaning, whether from description or depiction, is in part a reductive process—the space of possible meanings is greater than the space of ways to express meanings—misuses, misinterpretations, and misunderstandings are as inevitable as successes, and both are instructive” (Tversky, 2011). It is important to remain aware both of these principles in order to maximize understanding and avoid confusion as much as possible. This paper explores the increasingly rich and complex features used to visualize data from the constructivist principles of meeting existing student experience and design for exploration as well as incorporating scaffolding to support the learner to actively develop their own understanding of the target topic in incrementally appropriate steps (Sawyer, 2014).

Method

Leaning heavily on the constructivist framework, my hypothesis is that more complex representation environments have the capability to enable effective communication and understanding of more complex meaning. However, increased complexity of any kind comes with risk of surpassing cognitive load if proper scaffolding is not in place (Sawyer, 2014). To attempt to test this hypothesis, scholarly articles and empirical studies were analyzed that studied the specific features found in the 3Data environment. Specifically, the effectiveness of visualization, skill development in visualization comprehension, animation, 3D, and VR were reviewed, along with research into combining multiple features together. Key terms were searched in the UNC library online database as well as Google Scholar.

Discussion

Effectiveness of Visualization

The graphical representation of information is tremendously effective. Schwartz and Heiser (2005) provide evidence that “[s]patial representations, both external drawings and internal images, exploit people’s sophisticated perceptual-motor system” (Sawyer, 2005, p. 283). Indeed, one study found that people could correctly identify 83% of pictures shown to them after going through an exhausting experience of viewing 10,000 pictures over the course of five days, a significant improvement over language memory tasks (Shepard, 1967). Clearly the perceptual-motor system allows for a very efficient means of processing high volumes of information which offers an incredible mechanism for communicating information.
Not all illustrations are effective, however. As Meyer describes in his article, “When is an illustration worth ten thousand words?” (1990), the learner, illustration, and learning goals all have to be aligned in order for meaningful learning to occur. While this may come as no surprise, it is still a helpful reminder that charts must be carefully crafted from appropriate data in a meaningful representation intentionally for specific learners with the aim of conveying a specific learning goal. Failure to address any of the individual components of this closed system will result in the failure to accomplish the intended outcome. Additionally, Meyer (1990) says that an illustration is not effective if the learner is already aware of the information attempting to be conveyed. While this may seem intuitive, it is worth noting as it should be considered with the design and development of any new visualization: if illustrations are presented with the general understanding that they have the specific purpose to impart new information, then a redundant chart may leave a learner worse off than simply omitting it.

**Skill Development**

Schwartz and Heiser (Sawyer, 2005) highlight that there is evidence that spatial visualization is a skill that can be improved upon through practice. Additionally, they have evidence that shows that spatial information can be perceived as difficult if it is not introduced appropriately with sufficient supporting context. This suggests that while viewing a complex graph may appear difficult to a new learner, it is not, in fact, the chart itself that is difficult. Rather it is the combination of steps required within one illustration to make sense of it. Once those steps are clearly presented, the overall perceived difficulty drops. Additionally, many techniques used in common among complex graphs can be learned and transferred by the learner across graphs. Scaffolding, therefore, is an integral component of building user comprehension and traversing increasingly complex graphical representations.

**Static vs. Animation**

Animation offers a great deal of opportunity to represent data in richer way than a static picture. Ainsworth (2008) provides examples such as pressure systems in weather maps, anatomical movement, or molecular movement which are good candidates for effectiveness due to their inherently dynamic nature. With improved technology, more sophisticated animations can be created that offer in increasingly large amount of detail and data.

Animation requires the same level of cohesion to design principles as other data visualization techniques. Animations are more effective when used to illustrate the effect of time on a system rather than simply animation for effect, such a word rotating around on its axis. Ainsworth (2008) cites research in multiple subcategories of animation to demonstrate that not all are similar nor have the same gains in learning. Further, not all categories have the same effects across all learners, and some areas allow the ability for learners to improve their skills in understanding. Finally, not all categories independent of each other all of the time. Therefore, each category must be taken into account individually when designing the visualizations. A final consideration is the fact that creating animations, and doing it according to the above principles, takes considerably more effort than creating static illustrations. It is important to take this into account when calculating whether the intended improvements in understanding merit the increased difficulty in creation.

**2D vs. 3D**
Paper and screens are both 2D, and these have been the primary media for displaying graphical information. Attempting to represent a three-dimensional space in two dimensions is possible, but there are trade-offs that must be made. Ultimately, some amount of information must be lost in this compression. To represent attribution data, data scientists take advantage of the same cognitive systems that are able to understand geographic maps. Rather than understanding the map to read North and East, attributions such as height and weight are substituted as the dimensions. Tversky (2000) claims that the capability to represent real space in an abbreviated space in a map is analogous to representing depictive space onto a graph. However, the attribution dimensions are unlimited, unlike the three special dimensions that we perceive. There are techniques that data scientists use to attempt to increase the dimensionality of charts, such as size, color, shape, etc. Increasingly, with the accessibility of necessary software and ubiquitous hardware, data scientists are also using 3D plots to add an extra dimension with which to show the information they are attempting to convey.

Since the overall purpose of data visualization is to create an artifact that efficiently communicates information, having an extra dimension to include this information appears useful. Often times it is, but, as shown throughout this paper, there are limits to its effectiveness. Simply, any information that only has one or two dimensions of attributes does not benefit, and in fact often suffers from, representation in three dimensions. More is not always better. Where there are three or more dimensions to communicate, care must be taken to ensure that the best techniques are utilized to represent the data considering a variety of factors including the complexity of the data, how it will be displayed, and the context (Dübel et al, 2014). For example, navigation and relative positioning can be more effective in 3D, but exact measurement and interpretation are improved in 2D, and a combination of both 2D and 3D can have further improved results.

Virtual Reality

Virtual Reality (VR) is a computer simulated three-dimensional environment that can be experienced by and interacted with in a realistic way by a user. VR environments are designed to be fully immersive, meaning that the user’s natural environment is replaced in a convincing manner via a headset. Unlike paper or a computer monitor which occupies only a fraction of the user’s field of view, when inside immersive VR, the user is only seeing the virtually created world.

Many applications have been explored with regards to education and learning VR. As technical advancement brings quality up and prices down, more novel applications are being developed and tested for efficacy. Dede and Dawley (2012) identify some of the ways which VR can be used in an educational setting: identify exploration via embodiment, virtual communication and collaboration, spatial simulation, experiential learning, and assessment. They highlight the research that has documented important and engaging learning in educational programs and signifies transfer of learning from VR to other contexts can occur. As with animation, there are limitations and tradeoffs when working with VR, and of the utmost importance is to appropriately match the learning goals to the design of the learning experience in (Dawley, 2012).
Considering that virtual reality is simply a computer simulated reality, anything is theoretically possible, including an authentic recreation of actual reality. Because of this, any learning experience is theoretically possible to simulate in VR. This said, Pantelidis (Stewart, 2010) provides a thorough review of when VR can and should be used or avoided. Some of the items included on his lists for when VR is encouraged include replacement for simulations, dangerous situations, high cost scenarios, high-stakes training, and opportunities for disabled learners. These are contrasted with a list of times when VR might be a poor decision: high expense to create, potential confusion, no substitute for reality, physical teamwork required, or potentially emotionally damaging.

These sources demonstrate the potential of VR as a powerful medium for learning, yet also highlight that careful thought needs to be put into the alignment between the learning goals, learning content, learning medium, and learner. Ensuring that there is a compelling reason to use VR (of which there are many) to conduct a specific learning activity will help create positive learning outcomes.

**Multiple Representations**

Software improvements (and decreased prices) have contributed to the increase in types of quality of data visualizations. Visualizations on screens instead of paper have the ability to be animated, allowing viewers to see changes over time or perhaps how datasets are affected with the introduction of a new variable. The data can be represented in a way that is interactive enabling the learner to take control or provide input into how the data should be manipulated or displayed. While 3D approximations have been achievable at an increasing quality in the past, now 3D models can be embedded in websites that allow the user to move the model to view from any angle and zoom in or out. Additionally, smartphones are now powerful enough to display augmented or virtual reality, and devices solely purposed for these functionalities have drastically improved in quality while dropping in price significantly towards near mass-consumer adoption.

As Shaaron Ainsworth (2018) states: “well-designed combinations of representations manipulate information to make their key (task-relevant) aspects more accessible to learners for beneficial cognitive, social, and affective processes” (Fischer, 2018, p. 99). Ainsworth continues to explicitly dissect the above sentence to describe the importance of each word chosen. Task relevance makes clear that representations are not, by themselves, right or wrong, but rather they can be appropriate or not given the context. Additionally, the combination of the representations is considered differently than the two or more representations taken on their own. One may be able to support or enhance another or provide a link to information already successfully covered for scaffolding. It is not the case that providing multiple representations can magically improve student learning, and, indeed, visualizations can prove misleading rather than informative. Again, more is not always better. Ultimately, however, when combined appropriately, these combinations of representations can increase learner outcomes overall.

**Discussion**

Increasing feature sets, such as moving from 2D to 3D or static to dynamic displays, enables additional freedom to explore higher dimensionality datasets. By adding these key features and
even adding multiple representations, increase the complexity level available to represent information within the learning media. Improved scaffolding and rich visual representations enable learners to better construct their own mental models and improve their understanding. More connections can be made, and conclusions drawn. The richer the representation environment, the more opportunity to build comprehension of data a complex nature. However, it is clear that representation feature-sets must only be as complex as needed and no greater, as redundancies may distract or confuse learners.

3Data, a startup company based in Austin, TX, provides a hosted virtual environment to present 3D data visualization. 3Data’s virtual environment offers a combination of all of the visualization attributes explored in this paper in addition to several others. The feature list includes the following: rich-formatted, 3D, interactive, animated, immersive virtual reality. In short: 3Data offers all of the modern data visualization features combined in one solution. As of this writing, no published studies have been done of 3Data’s platform, nor are there any known studies available on products which offer the same or approximate feature set. This paper was to provide a foundation upon which to support a hypothesis about the effectiveness of specific types of visualizations which are enabled through the platform.

This paper has explored the research on a variety of features available in modern data visualization to explore how they can be used most effectively in communication of complex information. The principles of the earliest scientists who studied the possibilities and limits of these visualizations hold as true with advanced interactive VR as they did with simple paper charts: concise, connect, appropriate. “Excellence in statistical graphics consists of complex ideas communicated with clarity, precision, and efficiency” (Tufte, 1983, p. 13). As the constructivists believe, learners are able to build upon existing knowledge using the relevant new information that is provided to them. In such a feature rich environment such as 3Data, learners will strongly benefit from appropriately designed complex information representations in a scaffolded, interactive way.
References


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