Virtual Worlds for 3D Visualizations

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Abstract. This paper presents an analysis and discussion of visual information representations in multi-user avatar-based 3D virtual worlds. We discuss benefits and issues of such environments for displaying scientific and information visualizations. In comparison to traditional two-dimensional representation forms, virtual worlds can be used to display more dimensions of information and illustrate data with real-world metaphors. Additionally, their collaborative and social character allows new ways to explore and experience visualizations. However, the design, implementation, and integration of three-dimensional visual representations in such environments are more challenging than for 2D representations. Thus, only a few visualization forms are reasonable. In this paper we reflect on implications for more useful 3D visualizations and introduce and discuss these on own examples.

Keywords. Visualizations, Visualization Techniques, Virtual Worlds, Immersive Worlds, Collaborative Environments

1. Introduction

In recent years there has been considerable interest in the examination of new user interfaces to display and explore scientific and information visualizations. Innovations in 3D technologies such as virtual reality devices offer new possibilities to graphically illustrate and interact with information in 3D. Although many authors have discussed and analyzed benefits of visual representations in 2D over 3D, the introduction of these devices and recent innovations in 3D graphics have renewed the discussion about application areas and potential benefits of presenting and exploring information in 3D.
An important issue of scientific (visual representation of scientific phenomena) and information (visual representation of data) visualizations is the successful representation of data connected to specific object or environmental information. The traditional forms of visualization technologies often use abstract elements, such as lines or pies, to illustrate data. Three-dimensional visualizations cannot only be used to integrate more dimensions and enable viewing information from different angles and views, but also to present data with visual metaphors. For instance, real-world models such as the replication of a city can be used to visualize data linked to geographical information.

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The current trend towards three-dimensional user-interfaces and interaction possibilities such as holographic display, 3D printing, and airborne haptics is and will enable new technologies for visualizations (Robert et al., 2014). Also, the current introduction of different virtual reality home solution and immersive gaming interfaces will allow affordable and more immersive solutions for different kinds of visualizations. One way to interact with these immersive virtual reality devices and make use of different 3D interaction interfaces are 3D virtual worlds. Virtual worlds can be avatar-based or designed from the first-person perspective. They can be designed as multi-user community environments, or as single-user worlds. In the following sections we will focus on collaborative community-based virtual worlds.
Although much research has been done using different 3D technologies to visualize data, only a few authors have described their experience with collaborative multi-user virtual worlds for presenting visualizations in a collaborative setup. Virtual worlds support several new options for displaying and exploring scientific information and abstract data. The 3D capability turns 3D virtual worlds into excellent environments for displaying and interacting with phenomena and datasets. Their collaborative character enables users to create, explore, and discuss visualizations with other users. Their ability to present data linked to geographical information and to use real-world metaphors make them into powerful tools to explore information in a realistic setup. However, the design and integration of three-dimensional information presentations in such an environment can be an overhead for simple datasets.
But what kind of visualizations should be integrated into virtual worlds? What kind of representational forms should be used to enhance the user experience? The aim of this paper is to describe and discuss potential application scenarios of virtual worlds for scientific and information visualizations, assess how well they are suited, and discuss prospects and issues.

2. Background and Related Work

In the first section, prior work that explores three-dimensional information visualization techniques is reviewed. After that, virtual worlds are introduced and work on 3D animations, simulations, and visualizations in such environments are summarized.

2.1. Information and Geographic Visualizations in 3D

Information and geographic visualization in 3D can be used for instance to represent multi-dimensional datasets, such as a mapping of data (e.g. amount of rain, air pollution) with geographic location to observe the situation in a 3D world model. Several authors have discussed challenges and conditions of using 3D visualizations. While well-designed 3D visualizations are often visually promising, not every dataset is suitable to be presented in 3D. For simple datasets, the implementation in 3D might be not better for presenting the information than in 2D. Physical data, however, often require a three-dimensional representation. Unfortunately, the design, implementation, and processing of visualizations in a 3D space are significantly more time- and cost-intensive. Advantages of using 3D applications to present data include the possibility to add additional dimensions and new viewpoints (Card, Mackinlay, & Shneiderman, 1999), and to maximize effective use of the screen (Robertson, Mackinlay, & Card, 1991).

Many authors describe positive experience with 3D visualization forms in different application areas. McCahill and Erickson (1995) discuss an early design for a three-dimensional spatial user interface for the information system Gopher. GopherVR[2] uses 3D visualizations for displaying information in the form of 3D scenes. The user interface reminds of a computer game and is based on early virtual reality experiences. They use different 3D models to represent common icons in the 3D space. The authors already identified several user experience problems, such as navigation problems, grouping and relationship problems, browsing problems, and different interactions issues. Robertson, Mackinlay and Card (1991) use cone trees to display hierarchical information structures in 3D.

Several systems use real-world metaphors as information space for displaying abstract data (Rohrer & Swing, 1997). One of the most famous examples in exploring three-dimensional interface forms for visualizations is described by Robertson, Card and Mackinlay (1993). The authors discuss the Information Visualizer, a user interface for an information retrieval system. They use 3D-room metaphors to illustrate workspaces. Rohrer and Swing (1997) visualize web search results in a 3D information space. They also use a 3D-room metaphor, where objects in the room link to specific information. Keskin and Vogelmann (1997) describe cityscapes metaphors as generalizations of bar charts to represent hierarchical and network information.

Andrews (1995) describes an early 3D visualization system known as Harmony Client. The system supports different three-dimensional visualization facilities. The Harmony VRweb 3D scene viewer can be used to explore scenes filled with information (e.g. a plan of a city offering information about sights of the city with embedded hyperlinks). Harmony's Information Landscape visualizes collection structures and users can navigate through this landscape. Different 3D icons can be used to represent different document types. Tomenski, Schulze-Wollgast and Schumann (2005) describe an approach to visualize temporal data on maps. They use 3D pencil and helix icons and combine them with a 3D map display to represent temporal dependencies on the map.

The above systems use 3D real-world metaphors, such as rooms, landscapes, or cities, to present information. Virtual worlds can enrich such environments with additional components, such as multi-user capability, which enables social and collaborative activities. In the next section, we will explore work on three-dimensional animations, simulations, and visualizations in virtual worlds.

2.2. 3D Visualizations in Virtual Worlds

Virtual worlds are defined as shared, persistent virtual environments underlying physical rules, where players, represented as avatars, can communicate with each other and interact with the world in real time (Bartle, 2004; De Lucia et al., 2009). They are efficient environments for representing three-dimensional objects, animations, and interactive simulations. Their multiuser support allows different collaborative and social activities. Hence, virtual worlds have become a popular tool for applications in areas such as training, simulation, or design (Benford et al., 2001). Different authors also describe the users' feeling of presence as a significant advantage over traditional

[2] http://www.floodgap.com/software/gophervr

communication platforms and communities. This feeling is also known as "being part" of the virtual world (De Lucia et al., 2009; Witmer & Singer, 1998.

Studies suggest using virtual worlds in particular for application scenarios that make use of their three-dimensional objects and their interactive nature (Pirker et al., 2013). There is only little work on the use of multi-user virtual worlds for displaying three-dimensional information visualization forms. However, several authors have described collaborative setups, which integrate 3D applications, animations, or simulations in virtual worlds, and which can further be used and extended to create scientific or information visualizations.

Pirker et al. (2012) describe a prototype system, the Virtual TEAL World, in the context of remote physics education. The virtual world is designed to teach students principles of electromagnetism and uses interactive three-dimensional simulations to display electromagnetic phenomena. The collaborative character allows students to remotely discuss the phenomena illustrated by the simulation and solve assignments in-world together. A similar approach is used to teach students programming concepts by visualizing the behavior of a sorting algorithm (Pirker, Gütl, & Kappe, 2014). Both examples use three-dimensional simulations and animations to make unseen phenomena visible. The collaborative setup gives students the possibility to learn and work together.

While many authors have described systems that use 3D visualizations for learning and training, we know little about virtual worlds for scientific and information visualizations, either for explanatory, or exploratory usage. Most studies present visualizations in three-dimensional single-user applications, which use real-world metaphors. These metaphors are perhaps the most well-known visualization form of data in 3D environments. They allow users to explore the content in a familiar environment.

Fokaefs et al. (2010) discuss the use of 3D visualizations in Open Wonderland. They use a city metaphor to display information and statistics about software and communication artifacts. The dimensions to graphically illustrate data are building types, building color, height of the building, and proximity within city blocks.

3. Application Examples

There are numerous application examples, which can take advantage of collaborative three-dimensional multi-user environments. In the following section we will discuss potential scenarios, implemented as a first prototype in the virtual world toolkit Open Wonderland, which illustrate visualization scenarios especially designed for 3D virtual worlds.

3.1. Open Wonderland

Open Wonderland[3] is a collaborative virtual world with focus on extensibility (Kaplan & Yankelovich, 2012). Several modules allow the integration of different three-dimensional visualizations and animations. Users are represented as configurable avatars and can use a text-chat, VoIP, and gestures to communicate. 3D models to

[3] http://www.openwonderland.org

design and create a virtual environment can be dragged and dropped into the virtual world. New features (such as visualizations) can be integrated in form of modules. Open Wonderland also provides different tools to enhance discussions, brainstorming, and collaboration. This includes virtual white-boards, the option to share applications, and immediately contribute pictures and documents either from the desktop or the web (by dragging and dropping a document into the virtual world client).

3.2. Scientific Visualizations

An advantage of presenting scientific visualizations in virtual worlds is the ability of visualizing phenomena in a multi-user environment, which is remotely accessible and supports collaboration. Proving an integrated shared environment for scientific visualizations to scientists will enable them to explore phenomena and work together on their research. They can meet in the virtual world and use it as platform for cooperative research, discussions, and brainstorming. Multi-user virtual world environments support collaboration in the form of VoIP communication, knowledge and data sharing, or working together on in-world shared applications. As many modern teaching approached (in particular in STEM education) focus on peer- and group-learning activities, the cooperative discussion of visualization is key to successful learning experiences.

By providing scientific visualizations to students, a learning tool can enhance their conceptual understanding of the phenomena. In particular, possibilities to interact with such visualizations can help them understanding the concepts.

In Figure 1 (a) (an example of the Virtual TEAL World), the physical concept Faraday's Law is simulated and concepts that are usually invisible (in this case field lines) are visualized. Figure 1 (b) illustrates the behavior simulation of different sorting algorithms with colored marbles. Both visualizations were designed as learning tools and implemented as modules in Open Wonderland (Pirker et al., 2013; Kaplan, 2012) and can easily be extended to meet the requirements of specific scientific visualization scenarios.

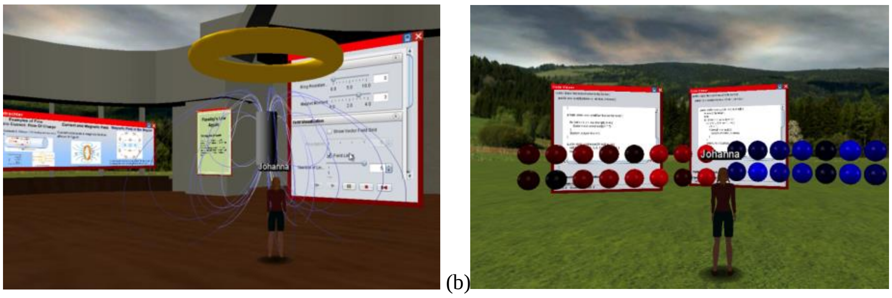

(a) (b)

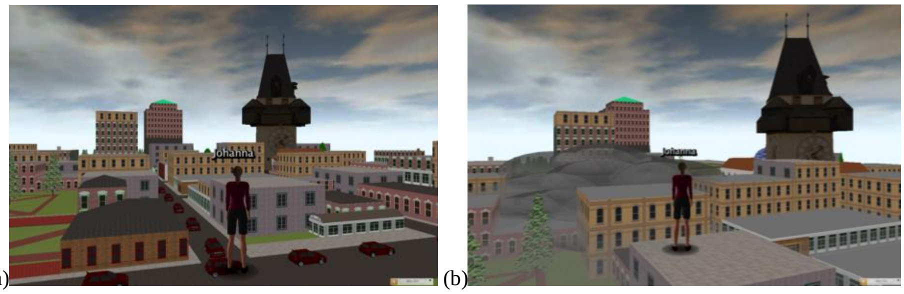
Figure 1. (a) Visualization of physics phenomena. (b) Illustrating algorithm behavior in 3D.

First studies with the simulation framework in Open Wonderland were conducted, which are discussed on the example of the Virtual TEAL World in detail in Pirker et al. (2013). The evaluation shows that interactive features of such visualizations in particular can optimize the learning outcome and the user engagement. One factor, which was particularly important for test users, was the integration of collaborative activities to create interesting and motiving learning environments. A first prototype of illustrating different sorting algorithm in an immersive learning environment is in development. This prototype will be first tested in a virtual reality setup (an immersive experience with a head-mounted virtual reality device) and then in a collaborative multi-user virtual world setup. With user studies we want to focus on open research questions such as (a) can immersion improve the user's understanding or perception of the scientific visualization, (b) does a collaborative learning setup improve the student's learning progress and understanding of the visualization.

3.3. Information Visualizations

Virtual world environments are well suited to illustrate different dimensions of data. In the following, we describe two application scenarios that use a geographical representation to present location-based data. In both examples, real-world metaphors are used to represent data. Users can either explore the environment alone, or meet other users to discuss and explore it together.

In Figure 2(a) presents statistics of traffic volume in different parts of a city. Simple three-dimensional models of cars are used to illustrate car frequency. Dimensions of the visualization can include the frequency, size, type, and color of the rendered cars. Since the virtual world supports high-fidelity audio, sounds could also be a further dimension to illustrate data. Figure 2(b) visualizes location-specific pollution statistics. Data is presented using the size and density of dust clouds to visualize the pollution in specific city areas, as can be seen in the figure.



(a) (b)

Figure 2. (a) Visualization of traffic volume in different parts of a city and (b) Location-specific pollution statistics. The avatar can be used to explore the environment in an immersive way. In a multi-user setup different avatars can explore and discuss the visualization together.

In both examples, users typically explore the environment by walking through the area to "experience" the visualization, or by flying over the city to get an overview. The collaborative and interactive settings enable the users to discuss the visualizations and interact with the environment. Through the virtual world's ability to enable users to experience visualizations together, perhaps new forms of virtual and remote information exploration can be studied.

First prototypes of these visualizations have been integrated into Open Wonderland. As a next step of this work-in-progress, first user studies and comparisons with similar two-dimensional applications are necessary to evaluate the prototypes. After that, an implementation is planned which is able to render data dynamically and considers the outcomes of the user studies. These studies are in particular important to answer still open questions such as (a) advantages and disadvantages compared to other visualization methods such as 2D map based visualizations, (b) would users like to walk through visualizations, (c) does the immersive character change the user's perception of the visualization, (d) would users benefit from the collaborative multi-user capabilities.

4. Conclusion and Future Work

In this paper we have discussed advantages and issues of using collaborative virtual worlds for scientific or information visualizations. To summarize, we believe that a collaborative setup in 3D virtual worlds can enhance the exploratory settings of such worlds. The prospect that virtual worlds for visualizations offer is that innovative collaborative exploration forms are possible. While scientific visualizations in collaborative 3D learning setups have been proven to be valuable learning tools, it is challenging to find application scenarios that are suitable for collaborative 3D information visualizations. Work on the introduced application scenarios is still at an early stage. Future work will involve the evaluation with user studies of the application scenarios with focus on the (a) advantages and limitations of collaborative aspects, (b) comparisons of the scenarios with similar 2D visualizations, and (c) advantages and limitations of immersive aspects.

At the moment, virtual world environments still face different technical (scalability, technical requirements, band width) and social challenges (learning new interaction-forms, prejudices against virtual worlds or game-like systems) (Benford et al., 2001). With the introduction of innovative and affordable virtual reality devices, 3D visualization forms in virtual environments provide additional options for displaying and exploring data and render it more interesting to users again. Also different enabling 3D technologies that support different input and display options are promising future supporters of 3D visualizations that can enhance the users' feeling of immersion. Thus, we will focus our research also on comparing different three-dimensional visualization strategies in immersive settings supported by head-mounted virtual reality devices combined with interactive interactions forms provided by tools such as the Kinect.

Whether three-dimensional information visualizations bring us more information or are less convenient for users has been widely debated. The present discussion demonstrates that well-designed visualizations in multi-user virtual world environments can open up new opportunities of exploring and discussing data in a collaborative and social way.

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