buenoSDIAs: Supporting Desktop Immersive Analytics While Actively Preventing Cybersickness

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Abstract

Immersive data analytics as an emerging research topic in scientific and information visualization has recently been brought back into the focus due to the emergence of low-cost consumer virtual reality hardware. Previous research has shown the positive impact of immersive visualization on data analytics workflows, but in most cases insights were based on large-screen setups. In contrast, less research focuses on a close integration of immersive technology into existing, i.e., desktop-based data analytics workflows. This implies specific requirements regarding the usability of such systems, which include, i.e., the prevention of cybersickness. In this work, we present a prototypical application, which offers a first set of tools and addresses major challenges for a fully immersive data analytics setting in which the user is sitting at a desktop. In particular, we address the problem of cybersickness by integrating prevention strategies combined with individualized user profiles to maximize time of use.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities.

1 Introduction

Immersive analytics, often addresses collaborative (co-located) analysis scenarios, e.g., in front of a large projection screen [3]. Instead, the recent trend of emerging consumer head-mounted displays (HMD) allows taking a step back. Not a step back in innovation, but literally back to the analyst's desktop. Today's HMDs facilitate the seamless experience of fully immersive analytics at the scientist's desktop, a concept denoted as deskVR [21]. This technology offers the potential to replace or at least supplement existing solutions for semi-immersive displays also called fish tank VR [18, 19]. These systems tend to suffer from a restricted field of regard, a restricted field of view, and a lower degree of immersion, despite full immersion having been proven beneficial in recent works in the analysis of various data [8, 13, 17]. Thus, it might be worthwhile to accept the extra costs for putting on an HMD while seated at the desk and executing classic data analytics workflows.Instead of replacing existing workflows and procedures, deskVR should seamlessly blend into existing processes and thereby extend the analyst's work with fully immersive visualization whereever beneficial.

The main contribution of this work is the presentation of a prototypical application that supports fully immersive analytics in a deskVR setting accompanied with a thorough discussion of the design decisions we took. With this application, we aim to explore the feature set which constitutes a productive framework for immersive analytics in a desktop environment. We see this work as a first step of a longer endeavor to explore the possibilities and challenges of deskVR in data analytics. As mentioned by Zielasko et al. [21], two classes of features are contributing to such a framework. The first class of features is not affected by the scenario and can thus be addressed by known solutions for common 3D interaction and settings. For example, the requirements for a effective collaborative environment remain mostly unchanged for other VR settings. The second class should or has to be designed specifically for this setting, as requirements preclude common solutions or support even better ones that benefit from a specialization to this scenario, e.g., travel.

Beside the general requirements raised by the deskVR setting as discussed above, one of the greatest challenges – not only for deskVR in particular but for VR in general – is the prevention of cybersickness [9]. Cybersickness induces (amongst others) nausea, dizziness and generally unwell-being, which restricts the amount of time a user can be immersed before s/he has to interrupt the work to rest and recover. Thus, cybersickness is a major issue that prevents beneficial use of fully immersive setups to be seamlessly integrated in data analytics workflows. Therefore, our prototype places a special focus on actively handling cybersickness. We implemented various techniques previously presented. e.g., in Fernandes et al. [5] and extended these approaches with user-specific profiles to compensate for individual differences.The effect of these techniques on productivity and time of immersion in fully immersive data analytics is currently subject of an ongoing user study conducted at our institute.

In the following section 2, we review existing applications and frameworks that actively or in theory support fully immersive analytics in a deskVR setting. Then, we present our prototype section 3 before concluding the paper with a summary and discussion in section 4.

2 Related Work

Over the past decade, various professional software solutions have been developed, which aim at embedding VR into everyday design and engineering workflows. For instance, the software framework Prospect[1] developed by IrisVR offers 'fully navigable VR walkthroughs that are true to scale'. The supported VR hardware (Oculus Rift and HTC Vive) implies a suitability for desk-based scenarios. Fuzor[2] and Autodesk's Stingray or Live[3] target similar functionality. Well established VR software distributors, such Virtalis (with VR4CAD[4]) or the ESI group with its IC.IDO[5] follow the same trend and made their software compatible with consumer HMDs. This upcoming trend for VR in engineering (referred to as *engineering virtual reality*), e.g., for car manufacturing or architectural design, has also been picked up in scientific work. Hilfert and König present in [6] a low-cost setup using various types of consumer VR hardware for a standing scenario implemented with a Virtuxi Omni treadmill[6] and Unreal 4 as software framework.

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[1]https://irisvr.com/prospect
[2]https://www.kalloctech.com/index.jsp
[3]http://www.autodesk.com/products/{stingray, live}/overview
[4]https://www.virtalis.com/vr4cad/
[5]https://www.esi-group.com/de/software-loesungen/virtual-reality/icido
[6]http://www.virtuix.com/

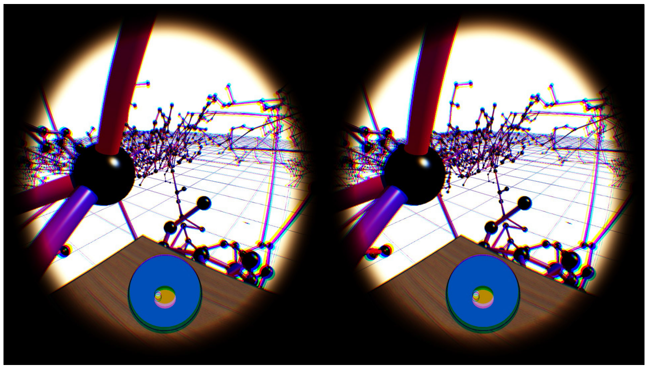

Figure 1: Screenshot of the prototype during the exploration of a large graph. In the lower part the a virtual desktop and a part of the travel interface is visible.

These approaches address engineering applications and scenarios. In the context of visualization, Kitware started a project to extend VTK with VR compatibility for Oculus Rift and HTC Vive support[7]. It interfaces with OpenVR[8] to receive the camera position from and to send rendered images to the HMD. However, the implementation of interaction is left to the user/developer of the immersive visualization application. Additional work on an extension of VTK has recently been presented by O'Leary et al. [11].

As outlined above, a broad variety of different approaches and software frameworks can be identified in engineering as well as in scientific visualization domain. Less research can be found w.r.t. the deskVR scenario, which is specifically focusing on a tight integration of immersive visualization into the analyst's everyday work – i.e. integrating it into a desktop setting. An exception is VRRRRoom [15], which utilizes desktop touch interactions in a deskVR setting to support radiologists. However, the aspect of cybersickness is less addressed although it is of high importance considering long-time use of HMDs. As the first step in this long research endeavor on deskVR, we present a prototypical application considering the specific full-immersive and seated scenario including active suppression techniques for cybersickness heading towards a tight integration of VR.

3 Application

In this section, we present our prototypical application for desktop-based, immersive data exploration (see Fig. 1). For the development, we considered the design guidelines proposed by Bellgardt et al. [1]. Following these, we will first characterize the environment 'desktop' in section 3.1 before presenting the application's functionality , specifically interaction techniques to travel in spatially rendered data (section 3.2), and selection/manipulation of data objects and representations (section 3.3), as well as methods to reduce the impact of cybersickness in section 3.4. Finally, the current feature set is summarized in a hypothetical scenario in section 3.5.

3.1 Environment

The special environment of deskVR, sitting in front of a desktop and wearing an HMD, is one of the factors that offers chances and simultaneously raises its distinct challenges. One opportunity, we are currently investigating, is a virtual copy of the user's pyhsical desk, which stays with the user (see Fig. 1), such as a head up display (HUD), and offers a tangible anchor from the virtual to the physical environment. Future research has to investigate the effects this has and whether this approach supports or hampers the analyst. However, assuming the desk's virtual representation is perceived beneficial, this opens up the utilization of, e.g., the keyboard (as described in section 3.3) or the desk's surface for interaction as utilized, e.g., in VRRRRoom [15]. Nevertheless, users' desks are often cluttered with objects. While some of these objects can be utilized for interaction, many objects are not of any relevance to the application. However, they cannot simply be ignored, as they might introduce hazards during wearing the HMD. While knocking objects on the desk over might annoy the user, bumping into objects with sharp edges or spilling hot liquids from a cup can be dangerous. This highlights the need to support user's awareness of her environment to prevent inefficient interaction and accidents.

Since the exact types, numbers, shapes, and properties of objects on the user's desk are not known, providing a generic way to recognize and display them is challenging. While our application does not yet deal with objects on the user's desk, different approaches are conceivable. Equipping all objects with fiducial markers might provide a first step, although this approach is not feasible in the long run, as users will not be willing to have markers on all their things. Using stereo reconstruction might be a better approach, e.g., by utilizing depth cameras. However, a solution that eventually fits the concepts of deskVR [21] has to require as little special hardware as possible to be accepted by professional data analysts and domain scientists such they can be integrated into their workplaces.

3.2 Travel

The seated scenario severely limits possible travel metaphors. This has already been discussed and evaluated in detail. For instance, Zielasko et al. [20] suggest a leaning and an accelerator pedal metaphor and leave the choice between either of the two to the user or the developer. In a nutshell, both methods travel in gaze direction or with respect to the body orientation, in case there is tracking information available. Then, the travel speed is influenced by the upper body's inclination in the leaning metaphor and by the height of the user's heel, which is tracked by a smartphone in the pants pocket, in the accelerator pedal metaphor. Furthermore, rotations are achievable due to turning the head out of specified deadzones. Both methods keep the hands of the user free for other interaction tasks. They are using body cues that potentially increase presence and decrease cybersickness. Additionally, they are conflicting with the user sitting as she is flying through the environment. Finally, the current set of available travel techniques is completed by a standard gamepad control.

3.3 Selection and Manipulation

Selection and manipulation, more than anything else, depend on the specific task. For an exclusively explorative analysis, if might be sufficient already to just provide the user with a well-working travel technique. In more complex cases, however, more sophisticated interaction with virtual entities, which make up the visualization, will be necessary. Thus, a framework for deskVR has to provide various building blocks that cover a large range of possible settings. Fortunately, most common interaction techniques work can be applied in a straighforward fashion in a deskVR scenario, because they usually require the user's hands and those are kept free by design (see section 3.2 above). Thus, the use of a wide range of interaction devices is possible. Moreover, natural, hand-based interaction are feasible, e.g., grasping and pointing, or gestures for triggering more complex interactions. We default to the latter, because it offers utilizing different other objects on the desk and the desk itself.

Wherever direct, hand-based input is not feasible, we try to benefit from the specifics of the desktop-based setup. For instance, text input is generally challenging in fully immersive environments [2]. But it gets straightforward if one can use the physical keyboard in the immersive environment while simultaneously preserving the illusion. Text input per se supports visual analytics workflows, e.g., because text annotations are often an important component of visual analysis [16]. Additionally, this interface helps to seamlessly transfer the insights gained during the immersive part of the analysis workflow back into an desktop application. Finally, using a physical keyboard

[7]https://blog.kitware.com/using-virtual-reality-devices-with-vtk/
[8]https://github.com/ValveSoftware/openvr

Figure 2: The upper image is showing a keybaord on a common office desktop that is tracked by a webcam and some markers to be prototypically placed on a virtual desk in the virtual environment (lower image). Thus the user can use her keybaord for text input in the IVE.

is beneficial, because we can reasonably assume users to be familiar with it already. McGill et al. [10] have explored an augmented virtuality based approach for locating and using the keyboard. Their approach is based on chroma-key, i.e., the background is a uniform color that can easily be removed and replaced by the virtual world, to leave only the keyboard and user's hands visible. While they report significantly improved typing performance, using a single-colored background is not feasible if the users are expected to sit at their own desks. In our application, we explore a novel approach that, while still being an augmented virtuality type solution, does not require the background to be a single color. We attach fiducial markers to the sides of the keyboard and to the surface of the desk (see Figure 2). Using a standard webcam, we track the position of the keyboard relative to the desk's surface. A quad is rendered at the keyboard's position, allowing the user to quickly identify the keyboard on their desks in the virtual scene. In order to enable the users to see their own hands while typing, the quad is textured, using a cutout of the camera image which accurately matches the location of the real keyboard. The resulting rendering – including visualizations of the fiducial markers for illustrative purposes – is shown in Figure 2. While this approach does not provide vision of the user's complete hands and forearms, at least the user's finger tips are visible. Initial feedback on this input technique are promising, yet a formal evaluation with respect to typing performance is left for future work.

Another advantage of mapping the physical desk into the virtual environment, is its use as a tangible surface, e.g., in order to place virtual menus onto it. Menus are an omnipresent system control element. They are useful in many contexts and play a key role in immersive analytics, too, for instance in order to control a host of different visualization parameters. To this end, we have conducted a small user study ($n = 14$) evaluating a mid air drop down menu that was controlled by a virtual representation of the user's hand and while the users liked the natural style of interaction at least half of the users reported exhaustion. Additionally, creating proper visual feedback that replaces other sensual cues was challenging. Both disadvantages can be mitigated by placing the menus on the surface of the desk.

3.4 Cybersickness

A key design goal of our endeavor is the reduction and outright prevention of cybersickness. There are various reasons that make us confident of rating this aspect critical. First, while cybersickness is a known but "far-away-from-fully-understood" problem in virtual reality research, its effects are in particular pronounced when using HMDs [12]. Second, we have to make sure that most, if not all, of the professional users are able to use this technology over prolonged periods of time without negatively affecting subsequent activities, be it working on other things or driving a car. In this regard, we have to keep in mind that cybersickness occurs very individually [14] and the number of persons being hypersensitive to cybersickness (about 5%) is not negligible [4]. Third, reducing cybersickness and increasing presence often seem to be competing goals, e.g., for travel tasks. Teleportation induces less cybersickness than continuous movement – with respect to sensory conflict theory [9] – and, thus, is used by a lot of current applications and games even though it reduces presence, which at the end is the main driver for using an VR system in the first place. Finally, exploring abstract or scientific data in an immersive environment is different from exploring architectural scenes and factors leading to cybersickness seem to be weighted differently, as well. As an example, flying through an abstract data set, e.g., a node-link diagram, is maybe inducing less sensory conflict when sitting in a chair compared to walking through a virtual hallway while sitting in a chair. In contrast, according to the authors' experience less symptoms of cybersickness might occur while playing somehow realistic games compared to navigating through an abstract data space. In summary, cybersickness seems to have some special characteristics w.r.t. deskVR which need to be taken into account, as a sick user is not productive and maybe even not being a user in future.

In an ideal scenario, we are able to outright stop and/or counter the effects causing cybersickness. This, however, is an ambitious task since the root causes are neither completely known nor can we counter all of them as of today, e.g., sensory conflict. Existing methods to reduce cybersickness are usually coming with specific drawbacks or are only usable within narrow design limits, e.g., reducing the field of view [5]. Thus, it seems to be not advisable to reduce the filed of view for every user and all the time, because somebody not effected by cybersickness wants to have the full field of view, while only the one feeling sick is maybe happy to be able to still use the system whenever her field of view gets limited.

These reasons led to the design decision to utilize user profiles in our prototype. In the beginning, this enables features like a gradual introduction to a system based on prefaces build on different user groups that are classified based on known to be relevant personal details, such as previous experiences, age, gender and so on. Based on the profiles the current well-being of the user, here called health state, is influenced and simultaneously the profile updated with respect to the made observations, which leads to profiles that adapt to their particular users over time. Still, this requires constant assessment of the well-being of the user. Within the current prototype, this is realized by asking the users to adapt their health state on their own, thus, whenever it changes, which comes with various drawbacks. The users usually do not want to care about their health state, they might forget to adapt it, they are usually not good in rating their own health state and finishing a not complete list, it is maybe too late to react when they are already sick. At the moment we are investigating how far this process can be supported by non-invasive biophysical measurements and literature already indicates that there might be a correlation between biophysical measurements and well-being (or the counterpart cybersickness) [7].Initial tests involving the heart rate and skin response measurements are promising. However, determining the health state is only the first step. Once determined, the application functionality and setting has to be adapted in a way that reduces cybersickness. The current underlying prototype, i.a., utilizes and manipulates parameters of the dynamic and static field of view, where the static one determines the maximum field of view and the dynamic the more restricted one used when user fastly moves and turns (c.f. [5]). Further parameters, which are manipulated, are the

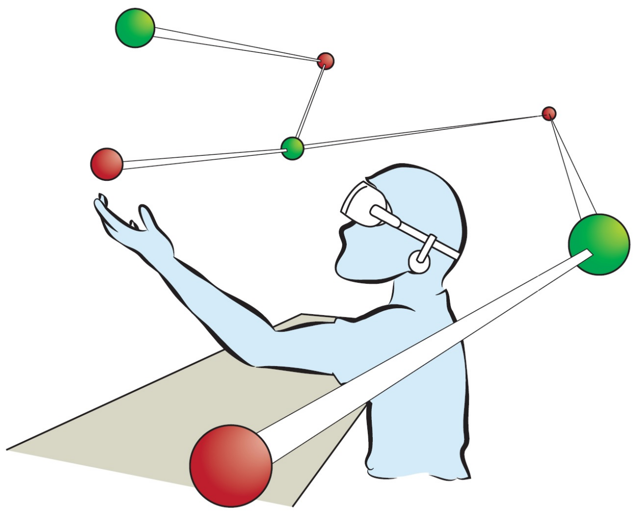

Figure 3: Concept sketch: A data analyst sitting in front of the desktop while wearing an HMD and immersively exploring a node-link diagram.

overall scene brightness, velocities, angular velocity, accelerations and even complete features are switched on/off, e.g., strafing.

3.5 The Whole Picture

In the following we draw a picture of the resulting application addressing the outline feature set by means of a user story. The analyst is sitting in front of her desk wearing an HMD (see Fig. 3). Her desk is substituted by a very similar one in the virtual environment. By tapping on the desk, she opens up a menu and loads a data set, here a time varying graph visualized as a node-link diagram (see Fig. 1). By subtlety leaning in her office chair she flies through the node-link diagram. When discovering an anomaly, she stops and selects the involved vertices by a hand gesture and annotates her observations by using the keyboard in front of her. The system knows from previous sessions that its user is vulnerable to cybersickness, especially with some time passing by and, thus, starts to subtle reduce her field of view after a certain time span. In some minutes it actually will suggest to leave the IVE for some time, before the analyst even starts feeling the symptoms of cybersickness.

4 Conclusion

In this paper, we have presented our ongoing development and evaluation of a prototypical application that targets the seamless integration of immersive analytics into existing data analysis workflows and workplaces. The current prototype has two cornerstones. First, it aims at maximizing the immersion via a virtualization of the user's desktop as well as natural hand-free interaction. Second, it actively reduces the occurring cybersickness. The latter is addressed by the use of user profiles, which influences a set of cybersickness countermeasures and their intensity.

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