# Remain Seated: Towards Fully-Immersive Desktop VR

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**ABSTRACT**

In this work we describe the scenario of fully-immersive desktop VR, which serves the overall goal to seamlessly integrate with existing workflows and workplaces of data analysts and researchers, such that they can benefit from the gain in productivity when immersed in their data-spaces. Furthermore, we provide a literature review showing the status quo of techniques and methods available for realizing this scenario under the raised restrictions. Finally, we propose a concept of an analysis framework and the decisions made and the decisions still to be taken, to outline how the described scenario and the collected methods are feasible in a real use case.

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

## 1 INTRODUCTION

Immersive virtual environments (IVE) have shown their potential in the visual analysis of scientific data or data with a spatial embedding in various applications [3, 35, 37, 46, 74]. Furthermore, research even suggests or found that abstract data sets, such as graphs, traditionally classified in the field of information visualization, can benefit from inspection in fully- and semi-immersive display settings [4, 18, 26, 36, 47, 71, 77]. A typical representative of a semi-immersive system is "fish tank VR" [65, 70], sometimes referred to as desktop VR. Those settings usually provide stereoscopy and sometimes even head-tracking but also suffer from drawbacks, e.g., in the field of view compared to fully-immersive systems, such as CAVEs. However, when considered as an integral part of a data analyst's workflow, the footprint of a CAVE and other projection-based systems is way too large to be seamlessly integrated. Simultaneously, our experiences with domain experts in various fields, e.g., neuroscientists, mechanical engineers and architects, show that the lack of accessibility, availability or seamless integration, is a major barrier for using IVEs as an extension in their established professional workflows. In consequence we, as virtual reality researchers, have to slightly adapt our goal from,

> *Make the experience, when accessing an IVE, so great and unique that it is worth to stand up.*

to,

> *Integrate an IVE seamlessly into an analyst's workflow and workplace so that she just uses it where it is beneficial.*

Note that the net gain of using an IVE created with the latter goal in mind has to be much smaller and only existent for parts of an analysis, to increase the overall productivity. When going down this road, fish tank VR solutions seem to be a perfect match, e.g., you can just exchange the conventional desktop display to a stereoscopic one and you are nearly there [63]. However, we believe that the grade of presence reachable within a fully-immersive system warrants the additional costs when considering the newest generation of head-mounted displays (HMDs) and their successors. While there is research supporting this [7, 22, 36, 47, 52] on one hand, there is also work which has found semi-immersive solutions to be more efficient [19, 51, 53]. The reasons for this may be diverse, but one recurring and unsatisfying reason might be that it depends on the application, on the data and on the tasks. Additionally, it remains very challenging, but nevertheless necessary, to map real world data analysis or real world workflows in general to entities that we can measure and thus, evaluate in a proper way [15]. Hence, the named counter examples themselves concede that shown results are either only proven to hold for tasks that benefit from a special *looking-in* perspective [19] or state that the resulting presence is consequentially lower [51]. Thus, a central question that has to be addressed is, which role takes presence in (abstract) data analysis? And perhaps even, what is presence in (abstract) data analysis? But this needs broader discussion in the community and for now we just need that the inspection of data in an IVE can help building up a mental model [13], i.e., a better structural understanding, of the data and thus, especially supports exploratory data analysis.

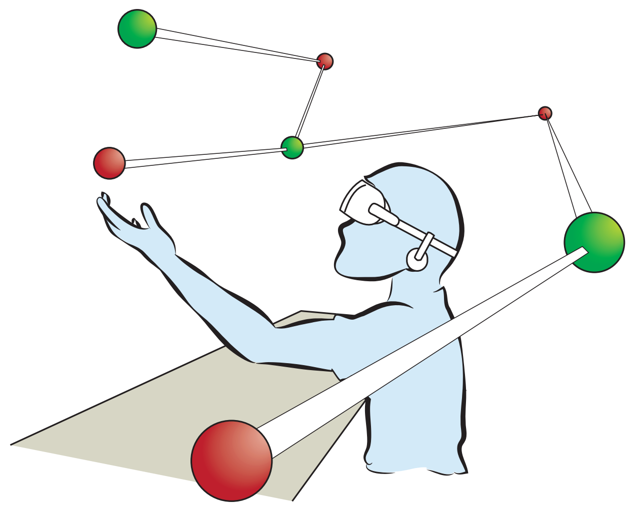

Figure 1: A deskVR concept draft.

In this paper we describe the scenario of fully-immersive analytics at an office desk and point out the resulting challenges and opportunities of this scenario in section 2. In the following, we refer to this scenario as ***deskVR*** to avoid ambiguity of *desktop VR* to fully- and semi-immersive settings. Furthermore, we give a literature review of the techniques that exist to address the described scenario and name the ones that have to be researched and developed in section 3. Then, we introduce the concepts of an analysis framework serving a deskVR use case and share the decisions and their reasons in section 4. Finally, we conclude this work in section 5.

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## 2 SCENARIO

In the previous section we motivated the scenario of deskVR, i.e, fully-immersive VR on a desk (see Figure 1). In this section we want to describe what this means in detail and how this scenario is constrained. The first two characteristics of deskVR are that everything takes place at an **office desk**, including screen(s), keyboard, mouse, a lot of paper and so on, with the user staying **seated** on her office chair. This addresses the requirement to integrate an IVE into the analyst's, who can be a domain expert, pure data analyst or scientist, existing workplace, which is the key-factor to become truly utilized. Hence, the office chair in front of an office desk is the most common scenario our solutions have to **integrate** to. Furthermore, sitting causes less fatigue than standing [17] and induces less cybersickness [43, 48], both becoming important factors when considering longer times of use, which in turn is a consequence of the application in a professional environment. The latter is addressed in more detail in section 3.4. Another important point is **acceptance**. On one hand, this includes the willingness of the analyst to wear and use the required gear and on the other, the used interaction metaphors should not require her to make jumping jacks or walk in place, while standing in front of the desk of an open-plan office. A basic seated position seams to provide less vulnerability to situations like this as well. A further criterion is that the analyst has to be able to **seamlessly enter and leave the VR** setting, as we should keep in mind that in most of the applications not the complete workflow takes place in an IVE, as a lot of things are just more efficient in a 2D desktop environment with mouse and keyboard interaction. Finally, the given setting is concluded by a fully-immersive display, which is only matched by an **HMD** today. Even when HMDs still face some challenges [42], this display technology massively caught up and is still catching up to large immersive projection systems [38] in recent years, e.g., became more affordable, light-weight, socially accepted while simultaneously becoming more enjoyable to use.

In the following section we list how these characteristics constrain and stimulate the techniques and methods needed and challenges to be taken into consideration to successfully set up and use the described scenario. We will make a survey of related work, finding out which methods are already there, which are adaptable to deskVR and which have to be developed.

## 3 REVIEW OF METHODS & TECHNIQUES

Integrating an IVE and making it accessible in the given scenario introduces special requirements for the hardware setup that are addressed in section 3.1. Furthermore, the user wants to explore the given dataspace and thus, should be able to interact with the given objects (see section 3.2). Hence, an IVE usually requires a travel technique. It is discussed if that is also necessary in an abstract dataspace, where scale is not defined, in section 3.3. Prevention and reduction of cybersickness (see Section 3.4) is an important field since the beginning of virtual reality research and becomes essential when considering the technology for professional and, thus, potentially longterm use [4]. Often conflicting with the reduction of cybersickness is the degree of presence that is achievable. Nevertheless, increasing the latter within an abstract dataspace (see section 3.5) is part of the drive that motivates deskVR. Finally, driven by the analysis background, collaboration (see section 3.6) and linking the data (see section 3.7) are aspects to be considered, too. The latter addresses the challenge of keeping track of the analyst's findings and the progress leading to them in-between sessions, different people and especially different applications (desktop/VR).

### 3.1 Hardware

The foundation of the deskVR scenario is the current generation of HMDs, their accessibility and their predictable evolution in the near future. They have become significantly cheaper, lighter and less cumbersome, have higher resolution and lower latency, are easy to integrate and even socially accepted. Additionally, the current HMDs provide at least basic tracking. However, more important is the fact that current challenges regarding HMDs are constantly addressed by an agile market. Thus, it is only a matter of time until the majority of HMDs, for instance, becomes untethered. In summary, the display technology for the deskVR setting is set and we are confident that the gap to large fully-immersive display systems regarding immersion on the one hand, and the gap to everyday technology as a notebook regarding simplicity and ease of use will be closed in near future. To serve the other sensory cues as well as for tracking there is one golden rule: everything should be kept as simple as possible and every additional hardware should be critically evaluated by the benefits it adds against the costs it incurs. Since any cost, be it a financial one or the need to change the current working environment, raises the barrier for the analyst to just use it.

### 3.2 Selection & Manipulation

When exploring a dataset, an analyst has to select and manipulate various entities. The positive part is that most of the common 3D selection and manipulation techniques [2] perfectly work in a deskVR setting as they usually require the user's hands. While using the classic desktop combination of keyboard and mouse is not always the best device combination in a 3D virtual environment, there are a lot of other possible controllers, e.g., gamepads or 6DOF point-and-click devices. Of course, it might be required to get rid of special controllers because of various reasons. A reason could be that its difficult to find them again when once put down away or it just feels better to use the hands. Thus, with tracked hands it is possible to use a direct touch interface [30, 41], which can increase presence but can also be more exhausting to use [14]. Tracked hands or fingers can also form a point-and-click device again together with an additional trigger, such as BlowClick [75]. Furthermore, there are solutions that rely on eyetracking [56], which may be a part of a lot of HMDs in the future. A final example is the keyboard, which is often the best solution to text input and usually is located on the desk anyways. Thus, it might be a good idea to make a keyboard accessible when wearing an HMD by fading it in [42], whenever required. In conclusion, various solutions exist. However, any of these should be rated according to fatigue [4], presence, integrability and how it coexists with the chosen travel technique (see section 3.3), next to common measurements as speed, precision and reliability.

### 3.3 Travel

Particularly in the analysis of abstract data one possible travel technique is to just rotate and scale the data set while *looking-in* [19] from the outside. However, in cases where this is the case we are not sure if a fish tank VR setting is insufficient, as it is unclear which benefits a higher level of presence would add. Navigation studies measuring task performance in non-abstract environments again show contrasting results [52, 53] but agree that the fully-immersive setting feels more natural and intuitive to the participants, especially in the case of looking-around. Nevertheless, datasets are often too large to be only over-viewed or the analyst explicitly wants to dive into the dataset to explore details or connections that otherwise are not accessible. A fully-immersive setting provides both options. When traveling through virtual worlds, real walking usually generates more presence than other techniques [68]. Nevertheless, this is hard to realize and not practical in deskVR. Following real walking, the walking-in-place metaphor was shown to work seated as well [33, 66, 67]. Furthermore, the use of a classic controller, such as a gamepad is possible. However, using body cues for locomotion has shown to increase presence [12, 49] and simultaneously decrease cybersickness [10]. A survey of different general travel techniques utilizing body cues and matching the deskVR scenario [76], found upper body leaning [49] and an accelerator pedal metaphor to perform well. There are other valid methods involving the user's feet, but of course requires them to be tracked [1, 58]. Finally, very important in a professional application but not challenging to solve in a seated scenario are the cat-problem, social acceptance or getting entangled with the cables of current HMDs.

### 3.4 Cybersickness

Cybersickness (CS) [39] is one of the major challenges when choosing an IVE as a platform to productively work in. This is, for instance, observable in a majority of newly developed entertainment content for HMDs, which for reasons of prudence often consciously avoid continuous virtual travel and replace it by teleportation metaphors knowing that this feels less natural and decreases spatial orientation [11], but simultaneously generates less CS as well [23]. But CS is not a phenomena exclusive to fully-immersive settings, but can also appear in fish tank VR [69]. However, once seriously affected by CS not only the user's productivity is reduced. It might even drive the user to stop using the tool altogether. Therefore, the prevention and reduction of CS are highly relevant problems to be addressed and solved. This challenge gets even bigger as CS often correlates with presence [24, 40] and usually shows a high inter- and intra-individual variability [55]. Nevertheless, possible countermeasures exist. First, the overall system latency should be low, as a high latency heavily induces CS [27]. Second, it is possible to, e.g, take into account when a user is using an immersive display technology the first time, by reducing the factors that usually generate most CS. Because it has shown in collected simulator sickness questionnaire scores [31], a subjective measurement that is often used in the context of CS, that users quickly get used to the new environment, often already starting with the second contact [55]. Furthermore, the level of CS increases linearly with the time of exposure, when comparable with the results in simulators [32]. It might nevertheless be a good solution to individually react on the high inter-individual variability and we introduce some initial concepts regarding this in a research prototype in section 4. A more active and flexible countermeasure is the reduction of the field of view [40]. When reduced dynamically in the right moment, e.g., when quickly looking around, this effect can even stay unrecognized [21]. Furthermore, making an application enjoyable to use may positively influence the grade of CS [40]. In summary, on the one hand, most of the current available countermeasures conflict with our goal to maximize presence, but on the other hand, are not necessary for all users. Thus, we introduce user profiles in our prototype (see section 4) that provides the user with a full set of functionality, e.g., regarding locomotion, when she feels well and restricts her when not, or in best case before she feels bad.

### 3.5 Presence

The degree of presence, i.e., how much a user feels as being part of the virtual environment or how much she feels present in the IVE, influences her ability to create a mental model of the environment [13], which then, should increase the task performance [6, 54, 60]. Maximizing presence already played an important role in the sections and decisions made before. Moreover, other methods help to increase presence and few are specific to a deskVR setting. For instance, embodiment has an important impact on feeling present in a virtual world [9, 61] and additionally increases the ability of proper distance perception [50]. Nevertheless, a sufficient tracking of the user's body requires an advanced tracking setup that is usually not feasible in a deskVR setting. Even when the user is sitting and, thus, not moving much, it is not advisable to just place a static virtual body in her position. While a different looking virtual body is usually tolerated to a relatively high extent [5, 20], mismatches in the movement of the real and the virtual body is usually recognized and negatively influences the sense of body-ownership [25]. Nevertheless, many interaction techniques require at least tracking the hands or trackers are easily mountable to an HMD, as in case of the Leap Motion, which introduces the possibility to draw virtual hands. But the environment of an office desk is not only restricting. Hence, inspired by embodiment, it is possible to map the desk as a virtual desk (see our prototype in section 4) or as a substitute for another object into the virtual world [59, 64]. The idea behind this is the same as in giving the user a virtual body that matches hers, in particular being an anchor to the real world. It is touchable and the user can rest her arms on it, without creating a conflict to the real world. Furthermore, it is possible to include other objects placed on the desk in both realities when useful, e.g., the keyboard [42]. An additional possibility is utilizing the objects that are available to substitute with something similar in the virtual world [59, 64]. Thus, a menu gets tangible by projecting it on the surface of the desk [73]. This does not only positively affect presence, but also decreases fatigue by simultaneously increasing performance in comparison with mid-air menus [14, 29]. A drawback or at least a challenge arising due to a user who is fully immersed by multi-sensory feedback is that the user does not longer recognize her real surroundings. This should be, for instance, addressed by monitoring people that come into reach [57] and maybe want to interact in reality.

### 3.6 Collaboration

One of the major benefits of large immersive projection systems is that they usually support collaborative work out of the box [18] and collaboration is essential in solving complex and eventually interdisciplinary analysis tasks. However, as soon as the technical challenges, such as session management and state synchronization, and the presentation of avatars are successfully addressed, this opens up the possibility to even cooperate in distinct places. When the user's body is tracked fully or partially, for instance, to give her a virtual body (see section 3.5) this can of course help in presenting an appropriate avatar for collaborators as well. The level of immersion in deskVR additionally helps in recognizing the collaborators as more present.

### 3.7 Linking & Provenance Tracking

The annotation, linking and tracking of the insights the analysts gained and the path she took to this point, within and between application contexts, are crucial, especially in a potentially collaborative and changing setting as described before. Since an analyst does not only want to find something interesting, she wants to annotate, save and restore intermediate findings and results in the IVE [45] and even more importantly wants to have a look on these findings with different tools in a 2D environment as well, and vice versa. Nevertheless, how important this consistency over applications may be, there are only a few initial approaches to solve this issue on a conceptual and general base at the moment [28]. In our prototype, which is introduced in the following section, we want to partially address this by embedding the IVE as a single view that the user can dive into at anytime in a multi-view analysis framework. In this case, everything is coupled and, thus, consistent at least within this context.

## 4 Prototype: Immersive Data Exploration

In the sections before we first restricted the scenario given by deskVR (see section 2) and then reviewed the methods and techniques that currently are available to set up an application serving this scenario (see section 3). In this section we now describe a first draft of an application living in this scenario. First, we want to roughly specify the underlying use case we serve along with the suggested solutions in section 4.1. Second, we will describe the concept we are developing for this use case and motivate the de-

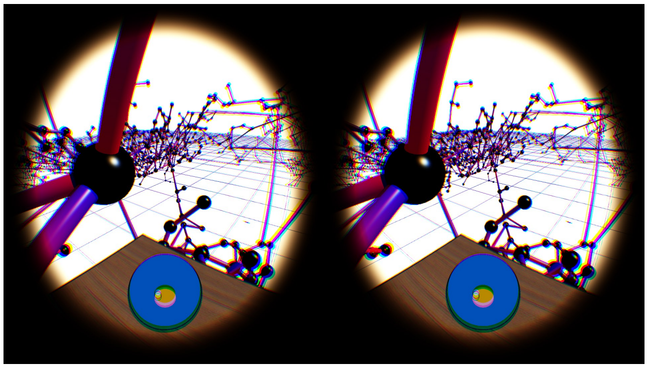

Figure 2: Stereo screenshot of the prototypical application, showing the analyst being immersed into a node-link diagram at her desk. The blue circle is part of the travel UI.

cision we make in section 4.2 and made referring to the methods described before.

### 4.1 Use Case

In our use case we have to deal with the relation between entities. Those are depicted as node-link diagrams, which are a visual representation of graphs. This representation helps an analyst gain deeper insights into the data, especially when spread out in 3D and inspected in a stereoscopic display setting [71, 72]. When extended to full immersion, this setting can induce the feeling of actually being present in the data, which then can further help the analyst in building up a mental model of the data. This mental model often is the start of discovering and finally understanding complex relationships. This is often a first step and a finding has to be further investigated or compared with other types of related data. To some extent this data or functionality can also be made accessible in the IVE, but as the analyst is sitting at her desk anyways, we do not desperately have to bring every application and functionality into the IVE, but just guarantee a seamless transition between desktop and VR applications.

### 4.2 Concept

In this section we want to describe the concepts and decisions behind a prototype we are developing (see Figure 2) utilizing a deskVR setting in the context of immersive graph analysis. Therefore, we refer to the structure of section 3.

**Hardware** Starting with the current hardware setting, it consists of an HMD, including an external tracking camera and a hand tracking device attached to the HMD, in addition to the general setup of an office desk, including one or more screens, a keyboard and so on. This allows unplugging the whole setup within minutes and bring it to another workplace in the same office or to a project partner on the other side of the world.

**Selection & Manipulation** The system control is accessible via a direct touch mid-air menu at the moment, but will be testwisely replaced by a menu on the surface of the desk. This should reduce fatigue and increase the performance in using the menu, due to being tangible. Additionally, we plan to utilize objects, such as the keyboard, for interaction and at the moment are investigating possibilities to reduce the additional tracking hardware that will be necessary to realize this. A substitute of the user's desk is displayed at all time, at least in parts, and will even fly together with her through the data space. This realizes an anchor between reality and virtual environment, and makes the keyboard and other tangibles on the desk continuously accessible without damaging the illusion. For the selection part we still have to evaluate direct touch against point-and-click techniques, but it is likely to result in a hybrid approach that combines the advantages of both, namely selecting distinct objects and having a natural feel. In general, we follow the goal to keep the user's hands free, which beyond allowing natural interaction [8, 62] also allows seamless switch to the keyboard or grab any tangible in reach.

**Travel** For travel we are working with an upper body leaning metaphor and an accelerator pedal metaphor [76] at the moment. The first has the advantage that it does not require any additional hardware, while it forces the user to sometimes look and perhaps even feel a little bit strange leaning in her chair. The latter method is less intrusive, but requires at least a smartphone kept in the user's trousers pocket. Again, both do not involve the hands of the user.

**Cybersickness** To reduce cybersickness we first implemented dynamic field of view reduction [40]. While the approach utilizes the fact that a user does not recognize the reduction in all situations, we thought about extending it upon this threshold, when the user is particularly vulnerable to CS. This, in the end, led us to user profiles, which initially are fed with information that potentially influence CS, as gender, age, experiences, vulnerability and so on. Those user profiles together with user feedback and a user history in turn influence the users *health function*, which then steers factors that may cause significant amount of CS. These factors can be the field of view, travel parameters, as acceleration and velocity, the overall brightness of the scene and so on. Even more radical countermeasures would be to lock or reduce functionality, as prohibiting the user from strafing, i.e., moving side ways, or even tell her to quit the application and take a break. But this should happen with care, as a user always has to be made aware of the system state and the reasons for it and should not feel patronized. The biggest challenge is that the health function really maps the current well-being and thus, countermeasures are prematurely used to prevent CS, because once occurred it is difficult to alleviate it. In the future, this might be supported by handy sensory that is able to deduce the current level of CS by heart rate, sweat or brain activity [16, 34].

**Presence** With the fully-immersive setting and the interaction methods we have chosen so far, we already took the goal of maximizing presence into account. Additionally, we create virtual hands when the user's own enter the field of view. Furthermore, we think that a plausible integration of the virtual substitute of the user's desk can really increase presence not at least by being tangible and visible.

**Collaboration** We do not have a concept of how to integrate collaboration into the application at the moment, while this is an important point to consider in the future.

**Linking & Provenance Tracking** As introduced above, we try to address the point of linking data and keep the analyst's findings and notes consistent between a native desktop and VR context by developing our IVE application as part of a multi-view framework [44]. This in the future enables the possibility to take a window showing a 3D node-link diagram of a part of the data that has to be analyzed, put on an HMD and dive into it in an IVE. When selected, maybe even annotated, something interesting the analyst put the HMD aside and everything is still there, the selected cluster of edges maybe even highlighted in another matrix view of the graph.

## 5 Conclusion

In this work we described the scenario of deskVR, i.e., a fully-immersive desktop setting, which seamlessly integrates with existing workflows and workplaces of analysts or researchers, such that they can benefit from the gain in productivity when immersed in their data-spaces. In this scenario, we also presented the status quo of techniques and methods available for realizing similar VR setups and showed potential gaps that should be addressed by research. Finally, we proposed a concept of a graph explorer and the decisions made and the decisions still to be taken to outline how the described scenario and methods fit a real use case.


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