The Value of Immersive Analytics

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Abstract— In recent years, research on immersive environments has experienced a new wave of interest, and immersive analytics has been established as a new research field. Every year, a vast amount of different techniques, applications, and user studies are published that focus on employing immersive environments for analysis procedures. Nevertheless, immersive analytics is still a relatively unexplored field that needs more basic research in many aspects and is still viewed with skepticism. Rightly so, because in our opinion, many researchers do not fully exploit the possibilities offered by immersive environments and, on the contrary, some even partially overestimate the power of immersive analytics. Although a growing body of papers has demonstrated individual advantages of immersive analytics for specific tasks and problems, the general benefit of using immersive environments for effective analytic tasks remains controversial. In this paper, we reflect on *when* and *how* immersion may be appropriate for analysis and present four guiding scenarios. We report on our experiences, discuss the landscape of assessment strategies, and point out the directions where we believe immersive analytics has the greatest potential.

1 Introduction

The research field of immersive analytics [3] is gaining increasing attention in the community, particularly in the areas of visualization and human-computer interaction. As shown by surveys, there have been several research peaks in immersive environments in the past [7]. The recent surge may be due to the technological advancements in consumer-ready head-mounted augmented reality (AR) and virtual reality (VR) displays, as well as the stronger inclusion of the analytical process in such environments. Even though more and more research is being produced each year, the field as a whole is still relatively unexplored. Due to rapid advances in technology, research is aimed at moving targets. Findings and conclusions that apply to one device may not be applicable to another device that has a higher resolution, a wider field of view, or any other change that improves the immersion experience.

Even though immersive analytics (IA) aims at multisensory interfaces, often the focus is on vision. Most researchers now agree that IA is not a panacea that overcomes all issues associated with 3D visualizations on screens and makes unfavorable 3D visualizations suddenly useful. The underlying drawbacks of these 3D visualizations [18], such as occlusion, remain even when viewed in an immersive environment. Nevertheless, many IA studies are conducted with abstract 3D visualizations, such as scatterplots, without comprehensive justification. In some cases, even 3D visualization variants that are generally believed to perform worse than 2D counterparts are compared based on their performance on different media such as screen vs. AR/VR. That is, many studies use abstract 3D visualizations in immersive environments, which have already been said to perform poorly in the past, instead of shifting the focus to other visualizations and application domains that are much more likely to actually lead to advantages in immersive environments compared to classic 2D screen setups.

This and similar trends made us wonder in how far many of the current efforts go into directions that do not exploit the full potential of immersive environments. While it is legitimate to revisit and reevaluate previous findings with new devices, the focus should be on approaches that promise the largest potential in the extended design space. AR and VR offer much more than just a medium for viewing 3D visualizations, for example, by greatly expanding the design space in terms of multisensory interfaces, interaction, navigation, and collaborative aspects. Similar to Dwyer et al. [5], we define the term immersive analytics very broadly and see it as an interplay of analytics, visualization, interaction, and multisensory experiences.

Based on that, our driving questions are: *Why, when, and how does it make sense to use AR/VR for analysis tasks?* First and foremost, we want to make the reader aware of (1) the fact that IA does indeed extend the design space of classic visual analytics, (2) the plethora of opportunities for creating new analysis, visualization, and interaction techniques, (3) potential risks and common pitfalls, and (4) underexplored, yet promising research areas.

Skarbez et al. [25] recently outlined a general research agenda for immersive analytics. In this paper, we add to their line of argumentation by providing four guiding scenarios that illustrate where we believe some of the greatest potential for immersive analytics applications lies and discuss the value of IA. We derived these scenarios from the experiences and the discussions among the authors. We conclude this paper with a summary of lessons learned, including pointers to promising research gaps, appeals to avoid common pitfalls, and general remarks on the topic.

2 Four Guiding Scenarios

We take a look at four scenarios in which we believe IA has the greatest potential. The list is not exhaustive, and there are certainly additional directions that are generally promising.

2.1 Situated Analysis

Scenario Augmented reality fosters the presentation of situated visualizations, that is, the embedding of visualizations in the real environment close to the object of their content. Due to the proximity of the information to the object it refers to, the connection can be easily understood. Embedding visual information directly into its physical context is usually not possible with classical user interface setups. The approach implicitly follows the principle of 'details on demand', as the data space is continuously filtered for information that is displayable in the user's field of view. Thus, only information that is potentially interesting to the user at any given location is displayed. While glyphs could serve as initial visualizations to provide a good overview, users could be allowed to interact with them to dive into even more details.

Examples A common example is the display of nutritional information as a bar chart or glyph visualization above each item in a grocery store, as illustrated by ElSayed et al. [6]. An example of what this might look like is shown in Figure 1. Also quite popular is the dynamic placement of labels in AR space. For example, Zollmann et al. [27] use AR to place labels next to buildings to provide the user with additional information about their surroundings. Additionally, situated visualizations could also be used to support user navigation by, for

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example, displaying a trail on the floor that leads to the desired shelf in a library.

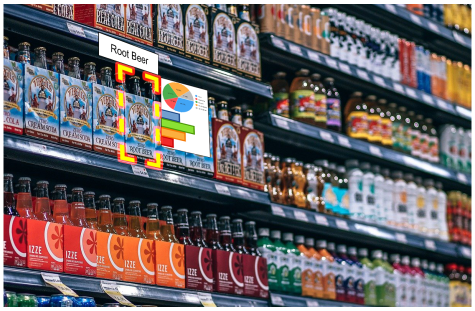

Fig. 1. Situated visualizations that display custom quality scores for each product on a grocery store shelf.

Reflections Situated visualizations and therewith facilitated situated analyses are certainly big selling points of augmented reality. The possibilities, once the technology is fully here and AR is widely accessible and used by the public, are endless. This reaches from adverts over informative and supportive visualizations to situated visualizations for the analysis of real-world environments or objects.

2.2 Spatial Data and Spatial Tasks

Scenario Analytical procedures that deal with the examination and analysis of spatial data can benefit from immersive environments. Spatial data often has an inherent spatial mapping in 3D space, while for a representation in 2D, some sort of transformation or abstraction must be applied. Of course, whether retaining the original structure is a significant advantage over abstraction depends on the individual data and tasks. Especially for spatial tasks, however, or when some spatial context such as the natural environment in movement analysis has to be integrated, the deployment of 3D visualizations can be useful. Once there is a clear motivation for using 3D, additional benefits of 3D visualizations can be exploited in immersive spaces. For example, anyone who has worked with 3D modeling software knows how difficult it can be to navigate in 3D space or to select a specific 3D region using keyboard and mouse. In immersive spaces, such tasks could be achieved more easily by providing direct interaction capabilities in the 3D space since no translation from the 2D input space to the 3D space is required. In addition to the benefit of an expanded, multimodal interaction design space, previous work has shown potential advantages of stereoscopic and immersive devices that could also be exploited, such as enhanced learning performance [8], memorization [23], spatial understanding [1], and orientation [24].

Examples Hurter et al.'s FiberClay [9] is a framework for exploring 3D aircraft trajectories in a VR environment (see Figure 2). Exploring the trajectories in an immersive environment allows the analyst to make use of intuitive spatial interactions, e. g., for selection while preserving the original shape of the trajectories. Additionally, stereoscopic vision helps to distinguish different trajectories and estimate their depth. Other examples can be taken from different domains, for instance, a scenario from the medical domain for analyzing brain scans in which a brain or associated data is interactively investigated in 3D space [4, 10, 20]. Similarly, in biology and chemistry, the same approach can be used to visualize and analyze microorganisms and molecules [19, 21].

Reflections Particularly for the pairing of spatial data and spatial tasks, the use of AR/VR is often promising. In those cases, there is a clear motivation for visualizing in 3D, and immersive spaces offer advanced interactions to facilitate spatial tasks in 3D. However, the need to visualize spatial data in 3D should be confirmed and first compared to 2D alternatives [2].

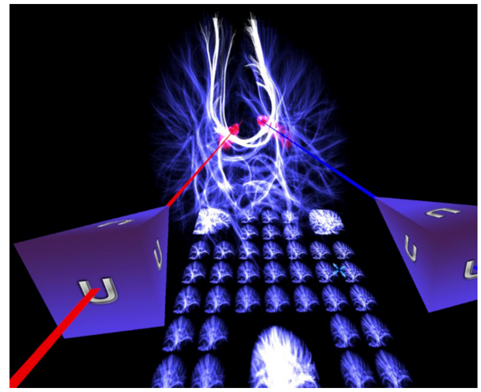

Fig. 2. Analysis of 3D trajectories in virtual reality [9]. Image courtesy of Christophe Hurter.

2.3 Collaboration

Scenario Immersive environments offer various advantages when it comes to collaboration. In our opinion, the biggest opportunity for improvement lies in remote collaboration. Using AR/VR, multiple users who are in different physical locations can meet in a shared virtual environment. This gives them a common visual grounding to support their discussion while allowing them to use familiar communication aids such as gestures, facial expressions, and simplified verbal expressions related to relative positions in space (e.g., "here", "left"). Of course, the extent to which this corresponds to real-world co-located collaboration experiences depends heavily on the technical implementation, such as the photorealism of avatars and the achieved embodiment in one's own avatar, e. g., through the perception of one's own body, the provision of a large interaction design space, and haptic feedback. Another advantage of remote collaboration is scale. For instance, while usually only a limited number of people can stand around a ship engine, in the virtual environment, a large number of people can simultaneously observe the 3D model of the engine - even from the exact same location when their avatars are rendered invisible. In addition to the advantages in terms of practicability, interaction, and communication, other social aspects could be exploited in the future. Since user avatars can be designed arbitrarily, it is possible to overcome social inequalities by designing them neutrally in scenarios where this is an issue. There are also possibilities for co-located collaboration, some of which overlap with those for remote collaboration scenarios. For example, when viewing a 3D visualization, all users can simultaneously investigate the same visualization while constantly seeing where the others are. This can improve communication compared to a setup where all users are observing the same visualization but on separate screens.

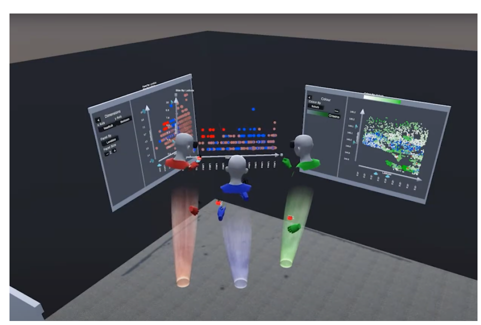

Fig. 3. Collaborative VR environment for the analysis of abstract 2D and 3D visualizations [16]. Image courtesy of Benjamin Lee.

Examples Lee et al. [16] presented Fiesta, a system for collaboration in physically co-located VR environments. Multiple users can join one shared VR environment to analyze abstract data visualizations together. The visualizations presented are not necessarily in 3D, and the VR environment can be used simply as a platform for collaboration without changing the familiar visualization basis. Another use case could be the deployment of immersive environments in teaching scenarios. For example, a real classroom could be replicated in a virtual environment so that students in remote locations can participate in and experience digital lessons similarly to real classes. Moreover, the use of AR/VR can improve social interactions and communication. The Corona pandemic, in particular, has shown that video chats cannot compete with face-to-face meetings in many aspects. Realistic imitations of real meetings using immersive environments have a lot of potential here.

Reflections In our opinion, collaborative analysis tasks, in particular in remote collaborations, can certainly benefit from IA. Currently, most examples are avatar-based VR applications. There are only a few examples where AR is deployed for this task, and there are several issues that need to be addressed for better AR-based remote collaboration. For example, AR applications share only a fraction of the overall environment since all collaborators have different real environments, and the display of avatars presents an obstacle because many AR devices are gesture-based and therefore do not have steady information about the position of the arms, making it difficult to display avatars correctly.

2.4 Presentation

Scenario Immersive environments can be appropriate for simply presenting information - but in a more engaging way. The use of the relatively new and unfamiliar environment is linked to higher levels of excitement, engagement, and entertainment [11, 17, 22]. Such effects would certainly help users to keep their attention and internalize information. However, it is not yet clear whether the effect will diminish as the technology becomes more familiar and the ‘WOW’ effect wears off. Another potential benefit of using AR/VR is that it can help users relate familiar measures, like distance, speed, or height to themselves, leading to better estimates of their absolute values. For example, when perceiving the 3D model of a house, it is easier to estimate its actual size without reference scales in VR than on the screen [15]. The goal of presentation is to convey information in the most complete and sustainable way possible. Previous studies have shown that immersive environments can support users’ (spatial) memory due to more engaging illustrations and spatial anchors. Therefore, if this feature can be exploited in a particular presentation scenario, this could be a good motivation for using immersive environments.

Examples For abstract data, spatialization can be useful to exploit the properties mentioned above. For instance, Zenner et al. [26] presented a way to represent circuit diagrams as 3D landscapes that can be explored in a VR environment. The authors conclude that the vivid presentation increased user interest but had no impact on model understanding performance. Another example is the remote access to reconstructed environments, such as museums, construction sites, or excavation areas. Users can walk through the virtual reconstruction of a real environment without having to move around physically. For example, in Figure 4, a reconstructed crime scene is shown in a VR environment to vividly convey the course of events in a court trial [14].

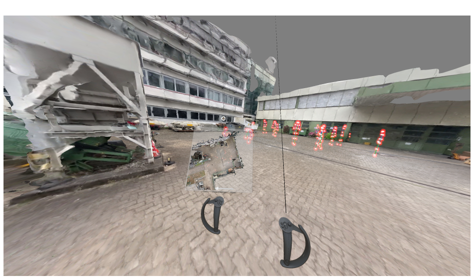

Fig. 4. A reconstructed crime scene is used to vividly present the sequence of events to a court jury [14].

Reflections While in conventional, screen-based analysis environments, a lot of effort is put into increasing the level of engagement through clever user interface design or even gamification, this already seems to be a side effect in immersive analytics. However, it may well be that the effect diminishes with increasing usage. In addition to potential benefits in terms of higher engagement, improved absolute value estimation, and memorization, immersive environments could also be suitable for information presentation during remote site inspections, lectures, or corporate presentations.

3 Implications & Discussion

As shown, there are several scenarios where we see great potential for immersive analytics applications. In the following, we outline lessons learned, address best practices, and discuss common pitfalls.

Immerse when adequate! Repeatedly, we have found examples where immersive environments were used seemingly for no reason - just because the technology was new and available. However, when using immersive hardware, there should at least be a hypothesis that promises added value. The actual use of the technology should then be based on the objective assessment of the added value. The extent to which AR/VR capabilities are exploited must also be carefully considered. It might not make sense to force the user to walk for spatial navigation or even to perform all analysis steps in an immersive environment just because it is possible. For example, if the IA approach is only beneficial for a specific subtask in an analysis procedure, it may make sense to use hybrid environments in which only part of the analysis takes place in AR/VR and the rest on a traditional screen.

IA is not the Holy Grail of 3D visualization! A particularly controversial issue is the visualization of abstract data in immersive environments. There are several evaluations where abstract data is presented in a 3D visualization to compare user performance in AR/VR and screen-based setups. In many cases, no clear motivation for using a 3D visualization is given, while there are visualization alternatives that are superior to the method used. Although viewing 3D visualizations is improved in some aspects when perceived in immersive environments, most of the drawbacks of 3D visualizations remain. For instance, occlusion, shifted baselines, depth distortions, and the difficulty of estimating and comparing certain visual variables, such as volume, remain major problems. Thus, even if the particular evaluation can show that AR/VR improves the analysis with the 3D visualization compared to a screen-based setup, it says nothing about the overall merit of AR/VR, as more powerful 2D alternatives for the screen were simply left out of the comparison (see also the “Straw Man Comparison” pitfall outlined by Munzner [18]).

However, there are certainly specific application areas where it might be useful to spatialize abstract data in order to take advantage of the aforementioned benefits of immersive environments, such as improved spatial understanding, orientation, memorization, or depth perception. For example, in the comparative analysis of 3D distributions of abstract data, the immersive, spatialized 3D variant with superpositioned 3D heatmaps was superior to the juxtapositioned 2D variant in certain tasks [13]. As shown in Figure 5, the vertical layout combined with the encoding of values on heightmaps facilitates the comparison of the two distributions. The user can slide one distribution through the other to identify correlations, offsets, and general trends. Another example where immersive environments can be useful for abstract data is the integration and exploration of abstract and spatial data, which has been discussed for some time, for example, for applications in the life sciences [12].

In this sense, the use of AR/VR should not be the only motivation for 3D visualizations. It may be that IA makes 3D more feasible, but the associated disadvantages must be outweighed by advantages to justify the deployment of the 3D visualization in question. It is worth mentioning here that IA goes beyond 3D visualization, and its added value can also be drawn for 2D visualizations from other aspects, such as multisensory feedback, enhanced interaction modalities, collaboration opportunities, and so on.

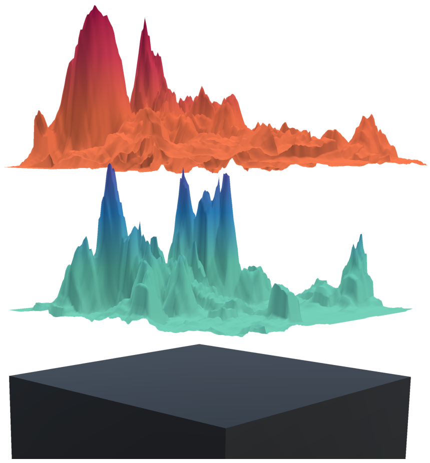

Fig. 5. Abstract data is spatialized, displayed as stacked 3D heightmaps, and observed in virtual reality for comparative analysis [13].

Assess the value of deployed AR/VR environments! Assessments of added value, as they are commonly used in practice, can be divided into three main groups. The first and weakest evaluation is that by example. In this case, a certain analysis procedure is performed in an immersive environment to demonstrate its general applicability without directly comparing it to conventional approaches. Usually, the added value is then asserted by argumentative hypotheses.

The second form of assessment is property evaluation. A specific aspect is singled out and compared across different media. An example would be a study comparing the memorability of users when observing a visualization on a screen and in VR. While this may provide the most reliable and substantiated evidence, it could well be dependent on many factors that would not apply in a particular application scenario.

The final group of evaluation involves comparisons of immersive and non-immersive analysis scenarios. This form of assessment can clearly identify the advantages and disadvantages of a particular IA system over the non-immersive counterpart to which it was compared, but because of many independent variables, the exact reasons are difficult to determine.

We argue that all three types of evaluation have their right to exist. While the first approach provides initial proofs of concept and new hypotheses, the second approach can quantitatively explore potential merits at a very detailed level. Their applicability and usability for a particular analysis use case can then be assessed by means of the third form of evaluation. For the last type of assessment, in particular, it is important to ensure that a fair comparison takes place. For example, in most cases, it does not make sense to assume the use of 3D visualizations when much more powerful 2D visualizations exist for the given task and then compare the performance of users working with them on screen and in VR. In case it is assumed that the use of an immersive environment overcomes the disadvantages of the 3D visualization, the 3D visualization in VR could be compared with the best possible 2D visualization on the screen.

Keep Going! Immersive analytics is still a relatively new field that lacks a broad scientific fundament. For instance, often criticized but not sufficiently addressed is the lack of established analysis environments, authoring toolkits, and standards for immersive analytics. Especially with regard to interaction modalities, no golden standard – similar to the iconic duo of mouse and keyboard for PCs – has yet emerged among the many options. Additionally, rapidly evolving hardware leads to the need for continuous re-evaluation. Findings that apply to a CAVE VR environment from the 80s do not necessarily apply to modern HMD VR setups. As there are many different areas of potentially very useful applications for immersive hardware, even away from immersive analytics, we expect the technology to grow in popularity, familiarity, and availability over the long term. And this could make it even more attractive for everyday IA procedures.

4 Conclusion

We believe that there are many potentials for immersive analytics and that there are ample opportunities for research in this area. In this paper, we presented four guiding scenarios to which we attribute great potential of immersive analytics: situated visualizations, spatial data analysis with spatial tasks, collaboration, and presentation. In addition to examples and justifications for our proposals, we also reflected on the overall situation in the field and pointed out common misconceptions and – in our opinion – best practices.

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