On Spatial Perception Issues In Augmented Reality Based Immersive Analytics

Martin Luboschik
University of Rostock
18051 Rostock, Germany
martin.luboschik@uni-rostock.de

Philip Berger
University of Rostock
18051 Rostock, Germany
philip.berger@uni-rostock.de

Oliver Staadt
University of Rostock
18051 Rostock, Germany
oliver.staadt@uni-rostock.de

Abstract
Beyond other domains, the field of immersive analytics makes use of Augmented Reality techniques to successfully support users in analyzing data. When displaying ubiquitous data integrated into the everyday life, spatial immersion issues like depth perception, data localization and object relations become relevant. Although there is a variety of techniques to deal with those, they are difficult to apply if the examined data or the reference space are large and abstract. In this work, we discuss observed problems in such immersive analytics systems and the applicability of current countermeasures to identify needs for action.

Author Keywords
Augmented reality; immersive analytics; spatial perception.

ACM Classification Keywords
H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities

Introduction
Within recent years, the domain of augmented reality has been pushed by the availability of affordable and powerful hardware (e.g., HoloLens). Such systems are now extensively applied and play an important role as for example in immersive analytics. Due to this development, the available rendering approaches have to be extended to deal
with broadened and new challenges. One of them is spatial perception. This issue has been extensively examined and discussed in the augmented reality community as it is a key for comprehensively relating virtual and real world objects (see e.g., [14, 23]).

In immersive analytics, spatial perception is fundamental due to the fact that spatial properties (e.g., position, size) are major attributes for encoding data [18]. Accordingly, they have to be perceived correctly in order to draw the right conclusions from the data.

Aware of this, augmented reality techniques have been applied mainly for the visual analysis of medical volume data [25], geo-spatial data [2], or industrial design studies, e.g., of cars [22]. These scenarios come along with some practical benefits related to immersion and spatial perception. First, the visualized data (e.g., human organs, buildings, cars) are somewhat familiar to the user and thus, the data themselves ease the understanding of locations, sizes, and distances. Second, the visualized objects are geometrically structured in a sense that the users can determine where object parts begin and end which partially helps to identify spatial object relations. Lastly, the data are often locally confined and/or related and thus, can be virtually placed on real world operating tables, buildings, platforms – providing an additional cue for spatial properties. Moreover, several visual cues exist that emphasize spatial properties and can be applied in the above scenarios.

In this work, we discuss common visual cues that support spatial perception in augmented reality and show to what extent they can be applied in a more generalized immersive analytics. In this context, we illustrate issues with regard to data that are abstract, evenly distributed, large or hard to relate to the spatial reference.

The remainder of this paper is structured as follows. First we present frequently used visual cues that support spatial perception in augmented reality to . Then we give a brief excerpt of plausible large scale immersive analytics applications and discuss the applicability of the presented cues.

Spatial cues in augmented reality

Natural cues which help humans to perceive distances and locations correctly have been studied for a long time (see e.g., [6]). They cover different efficiency ranges (personal, action, and vista space, see [23]) and categories (pictorial, kinetic, physiological or binocular depth cues, see [8]). Obviously, all of those should be reproduced in augmented reality systems to provide a distortion free spatial perception. Kruijff et. al. give a good overview of different open problems to achieve this goal and the respective research [14].

Among the fundamental aspects to be considered in augmented reality are linear perspective, relative sizes, motion parallax, binocular disparity. In addition, other visual cues exist that if implemented can dramatically improve spatial perception. Following we describe the effects of common ones and how they have been utilized in augmented reality.

Shadows

The importance of cast and attached shadows on image perception is reflected by repeated research in perception science (see e.g., [1, 19, 31]). Figures 1a–c show a popular example of shadow effects on position and shape perception as well as the ambiguity caused by missing shadows.

The purpose of realistically implementing shadows in augmented reality is to provide information on how the virtual objects are related to a real world reference and to facilitate a natural appearance. The virtual shadows allow for a comparison against the cast and the attached shadows of real world objects. Thus, the interpretation of the real world lo-
cations, orientations, and sizes allows to indirectly infer the virtual objects’ properties.

The effects of shadows have been studied in 3D computer graphics as well (e.g., [11]). Starting with different offline processing approaches (e.g., in [7]) shadows have been consistently implemented for augmented reality purposes. Nowadays several techniques are available that allow real-time rendering of shadows in augmented reality scenes (e.g., [10, 21]). They all capture and approximate the lighting conditions of the surrounding real world and apply this information to the virtual objects. The positive effect of virtual shadows on spatial perception in augmented reality applications has been reported repeatedly (e.g., in [4]).

Occlusion
Occlusion is a rather general depth cue as it simply conveys which object is in front of another. Thus, mutual occlusion of virtual and real world objects is an important aspect to spatially relate both and to communicate depth correctly. The positive effect of incorporating occlusions on correct depth perception has been reported for instance in [27].

A specific problem related to augmented reality systems is how to determine the depth of real world objects. With that information available – for instance from attached markers or a given 3D model (e.g., in [5]) – it is relatively easy to identify occluders and occluded parts of virtual and real objects. Subsequently, these properties have to be conveyed comprehensively. Different approaches are used to modify the appearance of occluding objects to uncover the hidden ones. They are basically similar to the illustrative techniques of ghosted or cut-away views (see e.g., [29] and Fig. 1d). Cut-aways can be found for instance in [5, 9] and transparencies in combination with masks are used in [20]. The X-Ray-Vision (e.g., [2, 12]) is a form of ghosted view showing phantom geometry of the occluders.

Additional Augmentations
The following paragraphs deal with different techniques, that introduce some geometry or use object properties that do not originate from the real world reference scene. Generally, they have been designed to enhance spatial perception in specific applications. Some of them are inspired by illustration techniques.
One approach that is helpful not only to perceive depth but also to quantify distances is the superimposition of grids (Fig. 1f). Aligning the grid with the user’s viewing direction (e.g., in [3, 30]) helps to determine egocentric distances. Moreover, embedding grids into the real-world reference, supports the recognition of exocentric distances (between objects, see e.g., [16, 27]). But the spatial relation of virtual objects and the grid can be emphasized further. One approach are virtual projections of objects onto the grid such as contours [30]. Another example are supportive lines that connect the virtual object with the grid or ground. This way, they convey the distance to the observer by the intersection point and also the altitude by their lengths (e.g., in [32]). In addition, they are independent of light sources (see Fig. 1f).

A technique known from video games to convey locations are top-down-views (Fig. 1f). Such views provide an overview of all virtual and real world objects to support spatial perception in augmented reality (see e.g., [27, 30]).

Another way to communicate spatial properties is to encode depth information directly into the depicted virtual objects. An obvious approach is to use colors for representing the depth values [28, 30]. Related studies can be found in the volume visualization domain [24]. Variations of this method are the adjustment of opacity or intensity depending on depth [17] and aerial perspective for larger distances [23]. In the same way, other graphical attributes can be used to depict depth: Depth of field [28] (see Fig. 1e) or symbolic frames (tunnel tool [3, 16]) are examples.

**Applicability in Immersive Analytics**

So far, augmented reality applications have generally focused on a rather small amount of virtual objects (few buildings, machine parts, pipes, human organs) in some kind of bounded reference space. One idea of immersive analytics is to make the ubiquitous data that surrounds the user visually graspable. Particularly, there are no restrictions neither on the amount and structure of data, nor the reference it is defined in. We can think for instance of volumetric environmental data sets (e.g., air pollution, weather forecasts) and to analyze or query that data on site. Other examples could be room-filling streaming data set of air conditioning or a rendering of sound propagation.

In the following paragraphs we illustrate, how the relaxed constraints on the visualized data complicate the application of the aforementioned visual cues. Although there is a wide range of aspects to be considered, we focus on the amount of data and its associated reference space.

**Large Data Sets**

The figures in [30] provide a good starting point for discussing large data sets. Those figures show five spheres with different depth enhancing visual cues. Inspecting the shadow planes reveals that the five cast shadows are partly fused. As a consequence, the shadows are somewhat ambiguous and thus, less helpful (Fig. 2a). This problem obviously increases with larger data sets and unfortunately, it also occurs with the other common visual cues presented above: Occlusions can only be depicted for a limited number of occluders, projections onto grids or planes won’t be assignable (Fig. 2a), supportive lines or depth encoding symbols will result in visual clutter (Fig. 2b), top-down views will bear severe overplotting (Fig. 2b), and so on. Other visual cues that encode depth for instance into color or depth of field are likely to interfere with the visualization design. They treat the important visual variable color [26] for depth perception (Fig. 2d) or restrict the data’s visibility (Fig. 2c).

Similar problems arise if the data are space filling or reveal no visual structure that eases object distinction. Complex structures (e.g., turbulent streamlines) make even small data sets hard to relate to depth cues.
Figure 2: Issues with larger data sets and larger reference spaces.

Large Reference Spaces
Regardless of the data amount, the reference space may also be of large scale in immersive analytics. Such large reference spaces will likely result in problems that are related to visibility issues. Beyond that, the highly restricted field of view in nowadays augmented reality hardware may cut off virtual objects. Figure 2e shows an illustrative example. Either due to the size of the reference space or due to a limited field of view, neither the cast shadows nor the base of the supportive lines are visible. Hence, these cues are not interpretable at all. An available countermeasure to this issue are artificial superimposed planes (see [30]). Unfortunately, such approaches come along with occlusion and distort the spatial perception themselves as they are in front of nearby geometry.

Additional problems arise if the reference space covers distances above 30m (vista space, see [23]). If the visualized data does not scale in size proportionally to the reference space, it will be difficult to perceive shadows, occlusion, supportive lines or differences in color. Due to linear perspective, the visual cues will shrink together with the visual representation of the data, making it difficult to perceive spatial relations (Fig. 2f).

Abstract reference spaces also suffer from hardly visible spatial cues or hidden references. A recent example are graph layouts on an immersive hemispheric display [15]. Looking at the spatial perception – not challenging or criticizing the approach – the question arises how the distances between nodes should be interpreted if this becomes necessary? The distance of opposite nodes could be the geodesic distance on the hemispheres’ surface or simply the real world Euclidean distance. Given such abstract spaces, there is no natural mapping between data driven distances and physically perceived distances. Hence, it is difficult to interpret the data unambiguously.
Conclusion
In this work we gave an overview of common techniques in augmented reality to support spatial perception. We illustrated problems of those techniques if they are applied to the complex field of immersive analytics without adaptations. Note that there are even more perception issues to be considered but they are rather specific to certain augmented reality display devices like monocular handhelds. Although our work focuses augmented reality in immersive analytics, the described problems partially apply to virtual reality systems or large high-resolution displays (see [13]) as well. In conclusion, there is a strong need for research on spatial depth cues in immersive analytics to make the overall goal of analyzing data by means of immersion achievable.

REFERENCES


