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ImmerView: Adaptive Multi-View Layout for Immersive Situated Visualizations

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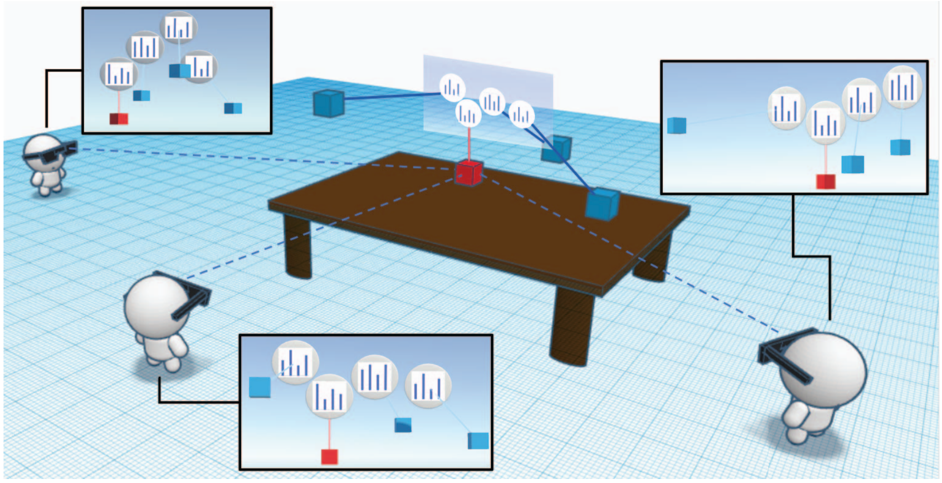

Figure 1: The adaptive multi-view layout approach for situated visualizations in the immersive environment: the views are displayed in close proximity to the objects, with relative positions reflecting the spatial orientation of users.

Abstract

Multi-view visualizations play a crucial role in presenting and comparing information within immersive analytics. These views can be positioned at various locations in the immersive environment, with a preference for attaching information close to the actual data, a concept referred to as situated visualization. While existing research has primarily concentrated on the multi-view layout and situated information based on objects' real-world positions, there has been limited exploration of users' subjective preferences for multiple views. These preferences might be influenced by factors such as the user's location, view direction, occlusion in the environment, and also correlate with visualization tasks. This paper introduces a method for developing a flexible layout for multi-view visualizations. This method takes into account the spatial arrangement of objects in relation to the user's position, viewing angle, and the object of focus. With this data, an optimal layout is generated for the views, ensuring that information maintains an equal distance from the user. Consequently, this promotes easier and more user-friendly information comparison, thus enriching the immersive analytics experience.

Index Terms: Human-centered computing—Visualization—Visualization techniques

1 Introduction

In recent years, the widespread availability of vast amounts of data with high dimensionalities has led to the prevalent use of multi-view (MV) visualizations across various fields [11, 13]. MV techniques offer users the ability to simultaneously explore diverse perspectives in data visualization, facilitating a deeper understanding of complex information through interactive approaches [17]. Many researchers have highlighted the effectiveness of MV techniques in addressing various challenges encountered in immersive analytics tasks, such as environmental occlusions or limitations in user views [16, 23].

Situated visualization emphasizes the inherent connection between objects and their properties, driving our focus on enhancing the situatedness between information views and the objects. Many designs have successfully adapted the view layout by utilizing the relative coordinates of objects with respect to the user, effectively aligning the positions of views with the objects' positions in the environment [12, 23]. This relative coordinate approach has proven effective in addressing situated visual search and localization tasks, particularly in situations where objects may be occluded or out of view [12]. Additionally, the common practice of placing views in the middle position of all objects and aligning them at the same height facilitates easy comparison. However, there has been limited attention given to considering users' actual positions in relation to the positions of the objects. For example, if certain objects are located too far or too close to users, it may become challenging for users to effectively observe the information displayed in the centered views. Furthermore, if all information views are aligned at the same height, it can lead to issues when multiple views need to be displayed concurrently. This uniform alignment might result in users facing difficulty in identifying the corresponding objects, especially when dealing with complex datasets. To enhance the effectiveness of the immersive visualization, it is crucial to consider a more dynamic approach to view positioning, which takes into account the spatial relationships between objects and users.

In this paper, we present an adaptive MV layout approach that considers the user's spatial position, visual perception and preferences. Our method prioritizes focusing the user's attention on a

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specific object and dynamically adjusts the MV layout in real-time by evaluating the relationships between this object's position and other objects within the user's view. The main contributions of our work associated with MV techniques in immersive analysis tasks are shown as follows:

- enhance the positions of the views to be close to the corresponding objects, thereby elevating the overall situatedness of the immersive analytics experience. By aligning the views more closely with the objects, we aim to enhance users' comprehension of the data and reduce potential search errors caused by visual perception.
- design the MV layout itself with positional cues, particularly aimed at facilitating situated search tasks. This feature empowers users to search for corresponding objects within the views, even when some objects are occluded or out of view, ensuring seamless and efficient data exploration and analysis.

Through our adaptive MV layout approach, we strive to create a more user-centric and effective immersive analytics platform, empowering users to gain deeper insights and make informed decisions from complex datasets.

2 RELATED WORKS

In this section, we review three related areas of research: multiple-view visualizations, situated visualization, and visual search in immersive environments.

2.1 Multi-View Visualizations

MV visualizations are techniques that present data from diverse perspectives, facilitating users' comprehension and minimizing misconceptions [15]. Typically organized as a set of views arranged in 2D space, each view depicts distinct encodings or datasets [22]. This layout enables users to associate and integrate information from various views, fostering linked view visual analysis [20]. Several 2D applications and systems, such as ComVis [14] and SightBi [21], offer interactive MV visualizations applicable across various domains, aiding users in accomplishing diverse visual analysis tasks. Recently, researchers have explored the extension of MV techniques to 3D and immersive visualizations, particularly in head-mounted devices [16]. For instance, Satriadi et al. [18] proposed the use of MV visualizations in the immersive environment for exploring maps at multiple scales and depths. This approach proves beneficial for tasks such as map searching and route planning, demonstrating the potential of MV techniques in the immersive context.

In addition, many studies have explored diverse possibilities of MV layouts, leading to various designs. MV systems with a smaller number of views often adopt fixed layout designs [6], such as the side-by-side views seen in BirdVis [9]. In contrast, more complex MV systems offer flexible view adjustment or management features, including focusing, splitting, and grouping, to enhance data analysis and optimize screen space utilization [20]. Moreover, research has demonstrated that spatial layout significantly influences human cognitive abilities. Spatial position encoding, such as layout, can be used to assist humans in memorizing information or revealing relationships [1, 20]. For instance, Wen et al. [23] proposed an adaptive MV layout method to facilitate linked view analysis during immersive analysis, while maintaining a high level of situatedness.

2.2 Situated Visualization

Situated visualization is a data visualization technique that enriches data by presenting it in spatial and semantic contexts, using augmented reality (AR) technologies to overlay information onto physical spatial scenes [24]. The situatedness of this approach is multifaceted, incorporating aspects of space, time, place, activity, and community. Space, in particular, plays a crucial role in establishing connections between visualizations and the physical world, aiding individuals in understanding the contextual relevance of the data [3]. An illustrative example of situated visualization is MARVisT [7], which leverages virtual glyphs to represent data. These virtual glyphs are positioned in association with real-world objects within the scene, effectively integrating data visualization with the physical environment. This seamless integration enhances users' understanding of data by contextualizing it within the spatial reality they observe through AR devices.

However, in immersive environments, situated visualization encounters specific challenges related to 3D space, including issues like occlusion of objects and environmental influences [16]. Many visualization designs have shown effectiveness in addressing these spatial challenges. For instance, Schall et al. [19] developed a mobile AR application using spatial interaction to assist in the maintenance of underground equipment. The visualization enabled previously obscured equipment, hidden beneath the ground surface, to be visualized effectively. In addition, MV is also commonly used to manage occlusion challenges in 3D spaces [8]. For instance, by incorporating gesture interactions alongside MV, users can selectively see-through real-world obstacles and access information about objects obscured by walls [5].

2.3 Visual Search in Immersive Environments

Visual search is a fundamental real-world task that requires observers to search for specific targets amidst random distractors [26]. A distinctive scenario is the search for out-of-view objects, which necessitates the use of visual cues to provide spatial information about the out-of-view objects and assist users in quickly locating target objects. On the 2D screen, abstract shapes or icons like arrows [4], wedges [10], labels [12], etc., are typically employed to encode real-world objects, serving as spatial cues to guide the visual search process.

In immersive environments, situated visualization, with its strong connection to real-world objects from a spatial perspective, holds great potential for navigational purposes in search tasks [12, 25]. Many studies have examined the utilization of embedded visualization and physical object positions as navigation aids. Bach et al. [2] introduced AR-CANVAS, employing embedded data visualization as navigational cues. Dynamic and interactive elements like highlights, icons, and text were incorporated to facilitate exploration in a library scenario, assisting users in searching for books. Additionally, Lin et al. [12] investigated the application of AR labels for situated analysis of both in-view and out-of-view objects. By mapping the physical positions of objects onto the positions or orders of AR labels, this approach enabled object search and analysis, enhancing the overall navigation experience within the immersive environment.

The Relevant literature has extensively explored the advantages of MV techniques in immersive environments from diverse perspectives. Despite recognizing the potential of MV and situated visualizations in immersive environments, there are still some issues required to be explored. One such issue pertains to target objects being located far apart from each other in the 3D environment. In such cases, it becomes crucial to investigate the optimal placement of information displays to ensure users can comprehensively understand the data and easily compare them. Moreover, users require an approximate understanding of objects and their associated information visualizations, even when these objects are temporarily out-of-view. Maintaining users' awareness of the overall dataset, despite objects being outside their immediate view, is crucial to facilitate data exploration and analysis in the immersive environment.

3 METHODS

Our approach to MV layout is tailored to amplify the contextual integration of visualizations within immersive analytics. This is achieved by considering both the user's spatial positioning and their viewpoint regarding the objects of focus. The algorithm captures relative positions among objects from the user's viewpoint and uses

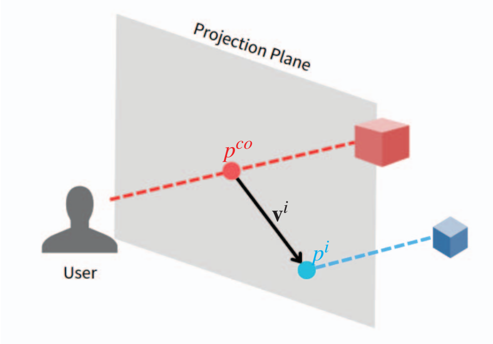


Figure 2: Calculate the position relationship, i.e. vector $\mathbf{v}^i$, between CO (red cube) and i^{th} object (blue cube)

this information to distribute MV layouts adaptively. This approach ensures that the visualizations align more closely with how users perceive the positional relationships, resulting in a more immersive and user-centric experience during data exploration and analysis.

3.1 Center Object Selection

The first step is to identify a center object (CO) that serves as a reference for calculating object relative positions and generating MV visualizations. We propose two feasible methods for CO selection:

- **Auto-select.** The object whose position is closest to the screen center is automatically selected as the CO. This approach ensures that the generated MV view can be easily observed by the user.
- **Manual-select.** The CO is manually chosen by the user in accordance with particular criteria. Although this method demands an extra effort to identify the object of interest, it results in a more anticipated MV layout that aligns with users' preferences.

3.2 Object Relative Positions

The second step is to obtain the position relationship among m objects in the scene. We represent these relations between the CO and the other objects by a set of vectors $\mathbf{v} = \{\mathbf{v}^1, \mathbf{v}^2, ...\mathbf{v}^n\}$, where n equals to $m-1$. These vectors represent a measure of the spatial arrangement and proximity between the CO and the other objects. To calculate the position relationship $\mathbf{v}^i$ between CO and i^{th} object (see in Fig. 2), we first set up a projection plane that is perpendicular to the link between the user and the CO. Then we project the i^{th} object and CO to the plane. $\mathbf{v}^i$ starts from the projected position of CO p^{co}, ended at the projected position of i^{th} object p^i, i.e.

$$\mathbf{v}^i = p^i - p^{co} \tag{1}$$

Finally we normalize $\mathbf{v}$ to obtain $\mathbf{v}_n$. The positional relationship between the two objects appears differently from different view angles (see in Fig. 3) .

3.3 Layout of multi-view visualization

In the third step, we design an adaptive layout technique for multi-view visualization that strategically arranges views on the projection plane corresponding to the distribution of objects in the immersive environment. Our approach revolves around the concept of Center View (CV), where the visualization of CO serves as the central point of the entire MV layout. The position of the CV, denoted as p^{cv}, is always located above the position of CO, with a user-defined bias incorporated. To arrange the remaining views, we utilize a positional relationship vector set denoted as $\mathbf{v}_n$, which is mentioned in Sect. 3.2. This vector set assists in determining the positions of the other views relative to the CV. The position of the i^{th} view p^i, corresponding to i^{th} object is calculated as

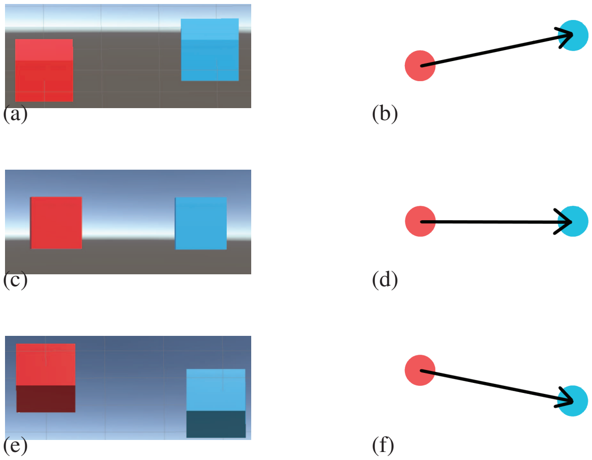

(a) (b) (c) (d) (e) (f)

Figure 3: The user observes objects from different viewing angles (left). The position relation captured from the user's perspective (right). Three view directions: (a,b) top-down view, (c,d) straight view and (e,f) bottom-up view.

$$p^i = p^{cv} + (2r\lambda){\mathbf{v}_n}^i \tag{2}$$

where λ is a positive integer that increases when two views occlude each other and r is the radius of the visualization.

Our layout method includes four cases (see in Fig. 4).

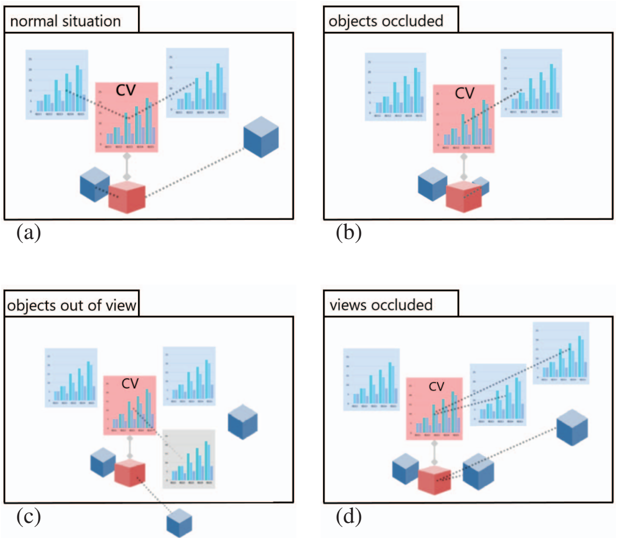
- Under typical situations (see in Fig. 4a), we arrange the MV visualization according to the formula outlined above.
- When objects are occluded (see in Fig. 4b),the visualization is adjusted to prevent occlusion.
- If an object falls out of view (see in Fig. 4c), the corresponding visualization is positioned within the user's field of view. The user can infer the object's position from the distribution of the MV layout.
- In cases where two visualizations occlude each other (shown in Fig. 4d), we increase λ to avoid occlusion.

4 DISCUSSION

There are several meaningful discussion points that we can derive from our layout design, as we explain as follows.

Center object-based layout. In our design, we carefully consider users' focus on specific objects for various reasons, such as when an object is positioned in the center of other target objects or when an object holds the particular interest, prompting users to compare data attributes with other objects. To address these considerations, we adopt a center object-based layout approach, wherein the center view is positioned directly above the center object, and other opinions are arranged around it. Compared to embedded layout, linked layout, and mixed layout [23], our layout design places significant emphasis on the view that users may find most important at the center. By intentionally reducing view distances during the comparison task and integrating other views around the center view, we aim to enhance users' ability to make meaningful comparisons and discern relationships among the displayed data. Simultaneously, we take care to preserve the overall situatedness, ensuring that users maintain a strong connection with the physical context while conducting their analysis.

However, the selection of the center object requires further consideration. At present, we propose two approaches: automatic selection



(a) (b) (c) (d)

Figure 4: Adaptive layout: (a) normal situation, (b) objects occluded, (c) objects out of view and (d) views occluded.

and manual selection. These approaches are founded on common understandings of what holds importance. For instance, the object situated in the center position could be deemed the most significant. Alternatively, users can manually select an object of focus that piques their interest. Nonetheless, these approaches have limitations, particularly when dealing with complex datasets, as they might not guarantee that the centrally placed object aligns with the true focus. Consequently, we recognize the necessity for more carefully deliberated methods for center object selection.

Layout adaptation. In the immersive environment, users have the freedom to move around and observe data from various perspectives. Consequently, the layout of 2D views should adapt dynamically as users change their viewpoints. This adaptability is essential to provide the most suitable and clearest distribution of information, ensuring an optimal visualization experience. For situated visualizations in the immersive environment, this becomes a crucial design consideration. Our adaptive layout approach addresses this challenge by taking into account both the user's view direction and the positions of objects. By considering these factors simultaneously, our method can cater to the preferences and needs of multiple users within the immersive environment. This adaptability ensures that users can interact with data effectively, exploring and analyzing it from different angles, while maintaining a strong connection with the physical context of the visualization.

Awareness of out-of-view objects. In complex data visualizations within the immersive environment, it is often the case that certain objects are out-of-view for users. Consequently, being aware of these out-of-view objects and their associated information becomes crucial for a comprehensive understanding of the data. Similar to the approach in [12], our MV layout also preserves the relative positional relationships among objects, even when they are outside the current view. Through our methods, users can gain an approximate overview of the spatial positions of the objects and their corresponding information. Users can effectively compare the information of out-of-view objects with those that are currently visible. This enables users to maintain an awareness of the complete dataset and know where to search for specific objects when they are not within the current view. This capability proves valuable in navigating complex visualizations and aids users in making well-informed decisions based on a comprehensive understanding of the data, even when objects are not immediately visible. However, we intend to conduct user studies to assess the efficacy of our approach in maintaining users' awareness across various scenarios.

5 LIMITATIONS AND FUTURE WORK

The current method in our work involves determining a projection plane for calculations based on the line connecting the user's eye position (or camera position) and the object. However, the current design and implementation approximate orthographic projection, where the projection rays from objects to the projection plane are parallel. This approach falls short of accurately simulating human visual perception. To achieve a more accurate simulation, it is necessary to consider the influence of the field of view (FOV) and use a cone-shaped projection plane.

If the scene contains a substantial number of objects, our current layout design may not perform optimally. When a large number of views need to be displayed, our layout design leads to densely clustered views. As a result, users may struggle to associate views with corresponding objects, leading to poor performance in the layout design. Therefore, the current approach is best suited for scenarios involving a small number of objects within the same scene.

Moreover, data visualization involves trade-offs. As mentioned earlier, many MV layouts prioritize the positioning of views to facilitate easy comparison of data attributes. However, this approach may lead to visual clutter and difficulties in accommodating numerous views, even though it simplifies data comparison. In our work, we take into account both the spatial positions of objects and the positions of users. As a result, the views' positions can reflect the relative spatial positions of the objects, even in the vertical dimension, enabling a more effective visual search in the immersive environment. Nevertheless, the information views are not currently aligned in the vertical dimension, which can pose challenges for users in information comparison tasks. As a result, in the future, we aim to refine our method further to address these considerations comprehensively. By taking into account all these aspects, we strive to enhance the performance and usability of our approach to better meet the diverse needs of users in immersive visualization scenarios.

6 CONCLUSION

In this paper, we present the potential of leveraging user visual perception of object position and positional relationships to advance immersive analysis. We propose a novel MV layout adaptation method aimed at enhancing the situatedness between information views and objects during immersive analysis. By incorporating layout as a means to offer positional information clues, our approach enables users to perform both information comparison and object search tasks seamlessly within the immersive environment.

As we continue the development of this research, our future work will concentrate on two main aspects: further optimization and user studies. We aim to gain a deep understanding of users' perspectives, considerations, and preferences when engaging in various visualization tasks using diverse MV layouts within the immersive environment. By conducting comprehensive user studies, we aim to gather valuable insights that will inform our design considerations and recommendations.

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