Interacting with Information in Immersive Virtual Environments

Austin R. Ward[1], Yiyin Gu[1], Sandeep Avula[2], Praneeth Chakravarthula[1]
[1]University of North Carolina at Chapel Hill, [2]Amazon
austinrw@unc.edu,yiyingu@live.unc.edu,sandeavu@amazon.com,cpk@cs.unc.edu

ABSTRACT

In this paper, we demonstrate the Information Interactions in Virtual Reality (IIVR) system designed and implemented to study how users interact with abstract information objects in immersive virtual environments in the context of information retrieval. Virtual reality displays are quickly growing as social and personal computing media, and understanding user interactions in these immersive environments is imperative. As a step towards effective information retrieval in such emerging platforms, our system is central to upcoming studies to observe how users engage in information triaging tasks in Virtual Reality (VR). In these studies, we will observe the effects of (1) information layouts and (2) types of interactions in VR. We believe this early system motivates researchers in understanding and designing meaningful interactions for future VR information retrieval applications.

CCS CONCEPTS

• **Information systems** → **Users and interactive retrieval**; • **Human-centered computing** → **Virtual reality**;

KEYWORDS

immersive search; information triage; virtual reality

ACM Reference Format:
Austin R. Ward[1], Yiyin Gu[1], Sandeep Avula[2], Praneeth Chakravarthula[1]. 2021. Interacting with Information in Immersive Virtual Environments. In *Proceedings of the 44th International ACM SIGIR Conference on Research and Development in Information Retrieval (SIGIR '21), July 11–15, 2021, Virtual Event, Canada.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3404835.3462787

1 INTRODUCTION

In this paper, we describe a system designed to study user interaction with abstract information objects (AIOs) in emerging immersive virtual environments (IVEs) in the context of information retrieval. We plan to use this system in upcoming studies to (1) understand the spatial design of a search engine results page (SERP) in IVEs and (2) interaction techniques with AIOs in IVEs. Within interactive information retrieval (IIR), researchers have studied the effects of presenting search engine results in two-dimensional interfaces for years [15, 31]. In addition, prior work has also investigated how users interact with information on a SERP and the underlying intent behind those actions [4, 19–22, 31]. For example, scrolling past a link may mean that a user is not interested in the information and clicking *may* mean the information is relevant [4, 19–22, 31]. While the interaction types such as clicks, scrolls, and bookmarks are well studied and established in 2D information layouts, we still lack a comprehensive understanding of how such interactions translate to 3D spaces enabled by emerging virtual and augmented reality head-mounted displays (HMDs).

Research on information presentation in VR has shown that spatially arranging information in IVEs can increase users' information bandwidth and aid with recall and simple visual search [5, 7, 23, 26]. However, few works have explored how these benefits of using immersive technologies could impact IIR. Recently, Ward and Capra [30] investigated different spatial layouts within the IIR context. Specifically, they investigated three conditions: (1) list – a vertical list of search results aligned in a flat plane; (2) grid – a 4x5 array of search results curved around the participant's forward view (140-degrees wide); and (3) arc – 2 rows of 10 results that surrounded the participant across a 220-degree arc. The authors reported that participants completed tasks that required a complete scan of the search result set significantly faster in the grid and arc conditions than in the Google-style list. Interestingly, although the tasks were finished fastest in the arc condition, the users disliked twisting their body to cover all the information. Instead, the users reported a preference for the grid of the two spatially immersive layouts. In our work, we build on Ward and Capra to investigate the ideal grid layout to realize a SERP in virtual reality. Additionally, we also investigate user preference in interacting with the information.

We make the following assumptions in this work: (1) the user is in an immersive virtual space (using a VR HMD) and needs to perform an information search and (2) the user is past the query phase of the search. This simplifies the experiment design by allowing us to focus our efforts on the SERP and interaction techniques in VR.

2 DESIGN MOTIVATION

Although significant progress has been made separately in IR and VR, relatively little work has been done yet at the intersection of both for abstract information needs [27]. Within IR, the information presentation and interaction has been heavily focused on a 2D layout, and more specifically on web-search [15, 20, 31]. In VR the focus has been more on embedding users in virtual worlds, which could be a simulation of a real-life physical space such as an office [25], or an imaginary world, especially for video games [1, 2, 29]. Furthermore, prior work has also investigated interaction techniques in immersive environments, with a heavy focus on hand-controllers and their haptic feedback to the user [3]. However, the question, "what are ideal mechanisms for interacting with the

[2] Work done while the author was at UNC Chapel Hill.

SIGIR '21, July 11–15, 2021, Virtual Event, Canada

ACM ISBN 978-1-4503-8037-9/21/07…$15.00
https://doi.org/10.1145/3404835.3462787

information objects in an immersive virtual environment?" still needs to be comprehensively answered. In this demo, we build on prior work and demonstrate a system that seeks to fill the gaps in existing literature and address two questions: (1) What is a search engine results page (SERP) in an IVE? (2) How do users prefer interacting with information objects in IVEs?

SERP in IVE: Ward and Capra [30] suggest that while users can benefit (faster task completion) from a wide horizontal display of information objects, there are also negative consequences. In their work, users found the wide placement to be physically challenging as they required significant physical movement such as large head or body motion. Although it took longer to complete the task, the users were favorable to the grid layout for the number of results displayed and list layout for its familiarity. But we still lack an understanding of what makes an ideal grid layout. Ward and Capra [30] implemented the grid such that the results curved around the participants spanning a field of view of 140 degrees. In this work, we mediate between the list and grid layout by investigating the number of columns to be presented to the user, which in turn reflects on the ideal field of view for presenting information around the user.

Studying this layout can help us in two ways. First, to investigate the number of columns and thus the field of view for which users prefer to have information around them warped. Second, this line of analysis positions us to study how users read through a grid, i.e., do they read row-by-row, column-by-column, diagonally, or randomly across cells. We argue that the order in which users read information has important implications for IIR. Prior work in IIR has both utilized the intertwined nature of relevant information and their position in a ranked list for both search algorithms and evaluation metrics. For example, consider a frequently used IR metric: NDCG@K [17], whose core assumption is that a highly relevant document appearing farther down a ranked list must be penalized. This assumption has been supported by multiple eye-tracking studies, which have found that users tend to focus on top-ranked results [11–13]. Prior work that has looked at ranking of results in IVEs used a ranking order that presented results (3D objects) of decreased relevancy in a spiral starting from the center view, but that design may prove to be difficult to use for text-heavy document surrogates typically read left-to-right, top-to-bottom [16]. Additionally, algorithms leveraging user interactions have also found a great benefit in utilizing the position of relevant information in ranked lists [18]. Therefore, we believe that understanding how users read through a grid is important for future work in IIVR.

Interaction techniques: Considerable prior work in IIR has established interpretations for user interactions on a SERP [20, 31]. For example, not clicking on the top result from a search engine could mean that the result was not relevant to the user's information need [20]. In VR, we do not have comparable interactions that directly map to web or mobile search or, going a step further, the action space for interactions on a SERP in VR. This study takes inspiration from prior work and relatable real-life motivations to explore three types of interaction techniques. The first is **Menu**, born of the WIMP (Windows, Icons, Menus, Pointers) paradigm [6, 24]. This style of interaction was designed for computer desktops and, due to its familiarity, found its way into VR and AR. The second is **Swipe**, which became popular with mobile interactions and are relevant to VR and AR due to its accessibility [24]. The final condition is **Place**, which parallels how we physically move objects in real life. While immersive environments do not always try to replicate a real-life setup, the space they create through the immersion makes it a curious case to investigate actions beyond the click of a button.

3 SYSTEM

We developed the Information Interactions in Virtual Reality (IIVR) system (Figure 2) to study how users interact with abstract information objects in immersive virtual environments. More specifically, we designed the system for two types of tasks: (1) information triaging and (2) comparing search results. This section describes the information artifacts and the different types of interactions supported by our system.

3.1 Abstract Information Objects

Our system uses a stand-in for SERP results through the abstract information object (AIO). An AIO (Figure 1) is a text, video, or image-based object used to convey information about an underlying web page or document to the user. Bowman et al. [8] designed AIOs in Virtual Environments (VEs) to help users create abstract structures distinct from the sensory and spatial structure of their VE. They used this strategy to describe or label objects in the VEs. In our work, we adopt this strategy to present search results as AIOs. For the current version of this system, we consider only text-based AIOs, which are similar to information cards [28]. Each text-based AIO shows the document title, the associated URL, and a snippet of the document text or image. We note that prior work in IR has also used similarly structured surrogates for search results in user studies [30].

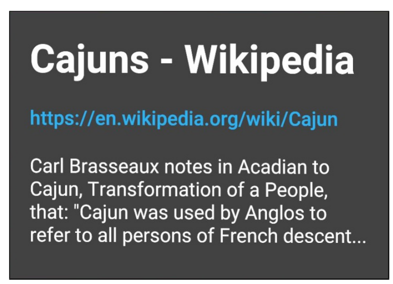

Figure 1: Abstract Information Object (AIO)

The demonstrated IIVR system aligns AIOs into "streams." An AIO stream consists of the top-aligned AIOs for our tasks. A single stream has three AIOs and appears as a column. When an AIO is removed from the stream, the remaining AIOs will slide into view to fill in the gap. For example in Figure 2, if the user saved the top AIO in the middle stream, its position would be replaced by the AIO below it. Our system can present a maximum of three streams or three columns. A stream can either be directly facing a user or wrapped around them. Prior work has shown that interfaces that wrap around the user, as if projected on a cylinder, are preferred. However, there is a limit to maximum tolerable body and head motion by the users, especially for information retrieval tasks [16, 30, 32].

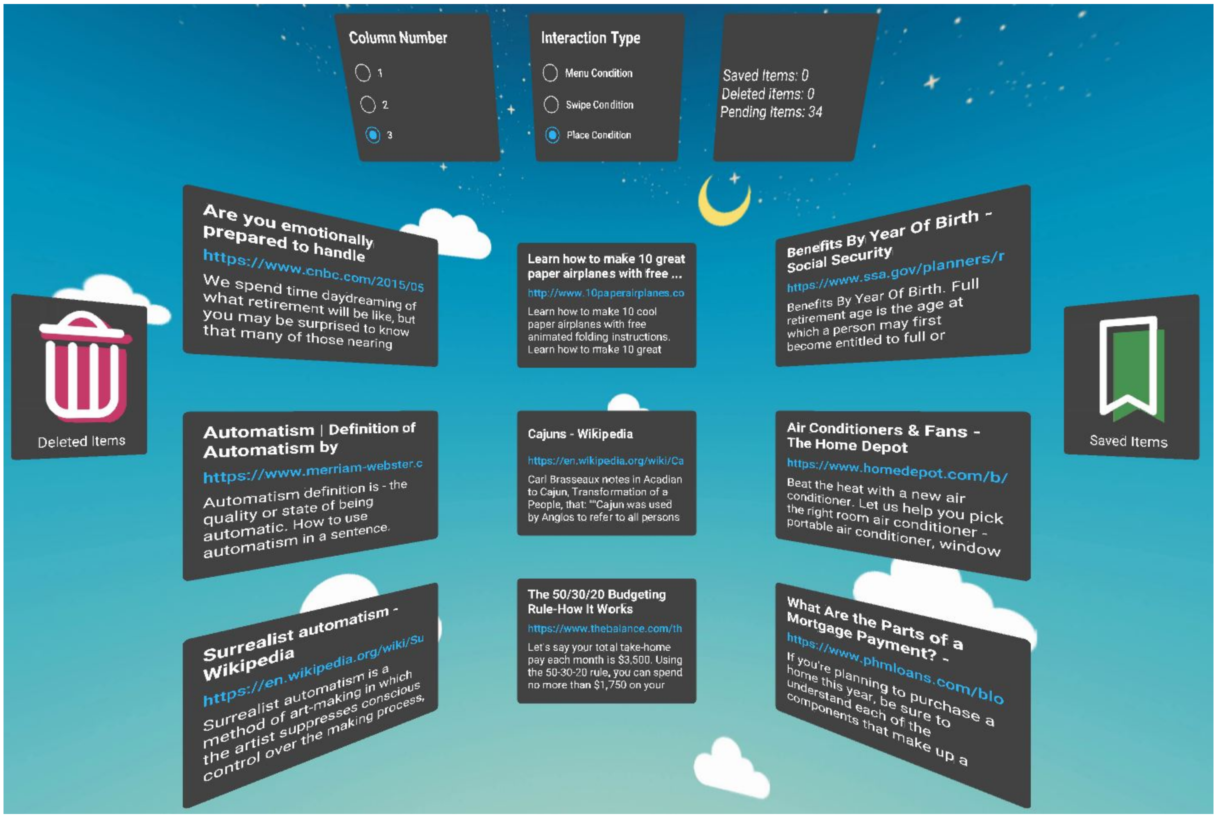

Figure 2: A zoomed-out view of the system in the 3-column layout, place interaction condition. The left and right columns wrap around the view of the user. The column number, interaction type, and statistics windows will be hidden for participants and replaced with a task description display.

3.2 Interaction Types

To study how users interact with different AIOs, we developed three interaction types informed by desktop, mobile, and real-world paradigms. Each interaction type requires the use of a motion-tracked controller for pointing and an action button that can be pressed and/or held.

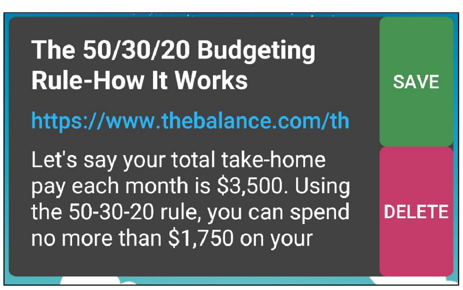

Figure 3: Menu Condition. The right Save/Delete buttons will appear when the AIO is clicked on. Clicking on either button will perform the respective action.

Menu: The Menu interaction type (Figure 3) was informed by the point, select, and context menu options that conventional desktop computers use. Users will use a controller to point at an AIO. Clicking on the object will present two options besides the AIO: Save and Delete. Clicking on the Save option will remove the AIO from the stream and mark it as saved in the system. Clicking on the Delete option will remove the AIO from the stream and mark it as deleted in the system. The AIO stream will then reposition the remaining results to the default position.

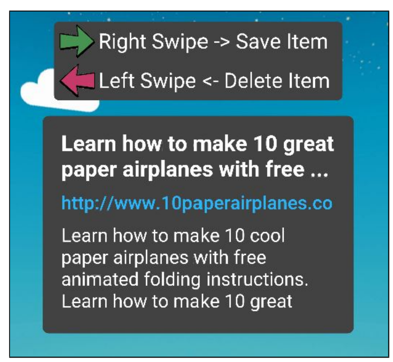

Figure 4: Swipe Condition. The swipe action instructions are displayed at the top of the center AIO stream.

Swipe: The Swipe interaction type (Figure 4) was informed by one-step gestures in mobile interfaces to perform actions. Users will use a controller to point at an AIO. Clicking and holding the select button will put the AIO into the "Swipe" state. The "Swipe" state only allows for dragging an item on a single axis (left or right only). Dragging the AIO right will remove the AIO from the stream and mark it as saved in the system. Dragging the AIO left will remove the AIO from the stream and mark it as deleted in the system. The AIO stream will then reposition the remaining results to the default position. If the user does not swipe the AIO far enough in either direction, the AIO repositions to the default position and remains in the stream. The distance to complete a swipe is 50% the length of the AIO's length, as to adhere to the mobile-influenced design goals and not require much physical effort.

Place: The Place interaction type (Figure 2) was informed by real-world interactions to physically file a document for later use or discard a document in a trash can. Users will use a controller to point at an AIO. Clicking and holding the select button will put the AIO into the "Place" state. Dragging the AIO to the saving icon (bookmark icon) will remove the AIO from the stream and mark it as saved in the system. Dragging the AIO to the deleting icon (trash can icon) will remove the AIO from the stream and mark it as deleted in the system. The AIO stream will then reposition the remaining results to the default position. If the user does not place the AIO into an action icon, the AIO repositions to the default position and remains in the stream.

4 IMPLEMENTATION

The system was built for the Oculus Quest VR HMD platform using the Unity game engine. The application logs all system interactions to an external database and used Oculus APIs for tracking head movements and head direction. The system uses VR UI Kit: Material Design System[1] for displaying the AIOs and DOTween[2] for animating the AIOs as they are added/removed from the system.

4.1 User Interactions

The system's goal is to *track* how users decide to save or delete information related to their tasks across the different information layouts and interaction types. For each task, the users will categorize the AIOs into "saved items" or "deleted items." Users will complete the actions in one of three ways (as described in Section 3.2) depending on the task-assigned interaction type. Using one of the Oculus Quest controllers, users can "click" on AIOs and select the menu options by pressing down the main thumb button (the **A** button). In the swipe and place interaction modes, users can drag objects when pressing and holding down the **A** button. While the swipe condition restricts the user's motion to a single axis (horizontal), the place condition is bounded by the field of view. Users can also drag the "Saved Items" and "Deleted Items" icons vertically in their field of view to re-position them to preferred spots, without overlapping with other system elements that may affect the system's functionality.

4.2 Tasks Supported

The initial version of the system will be used to study post-query triaging tasks in an information retrieval context (i.e., the user is presented with an information need and asked to triage the information stream based on the AIOs relevance to the task). Our triaging tasks are motivated by prior work on triaging a set of documents from a standardized query [10]. The AIOs will be used instead of full documents in our studies. Each task is assigned a set of relevant and irrelevant search results presented to the user as AIOs. Participants will be instructed to save all information objects relevant to the given topic and delete the AIOs that are irrelevant until the page is empty. For example, one of the trials might ask *"From the given search results, save all results that will help you understand the topic 'How to plant a tree.' Delete all irrelevant search results."* Though the system layout resembles a search system, users will not issue queries, browse, or paginate through the results. The tasks will only require the user to interact with the AIOs to perform a relevance judgment to save or delete the AIOs.

4.3 Interaction based measures

Informed by performance, process, and usability measures collected by prior IIR subjective user studies [22], the IIVR system is designed to record users' interactions with all system elements (e.g., clicks, drags, "mouseovers" - when an AIO is pointed at by the cursor, aborted drags) and their use of the system functions (e.g., saves, removes). It will also record the time-to-completion for tasks and the correctness of the user responses. Post-task questionnaires will compliment the interaction data collected from the IIVR system. Questionnaire items adapted from the NASA-TLX [14] will help users to report their perceived workload in a given condition, and items adapted from the system usability scale (SUS) [9] will help users to report their perceptions of the system usability in each element. In addition, we will use the questionnaires to record the user's preference for the interaction types and information layouts.

5 DISCUSSION

We designed and developed the IIVR system to study questions surrounding user interaction with information in immersive virtual environments. While there has been considerable work in IIR on how users interact with information within the context of information seeking in 2D displays, an understanding of it in an IVEs is still lacking. We take early steps to study this space using our system, for which we designed three interaction techniques. While the first two are inspired from interaction in desktop computers and mobile phones, our real-life interactions with physical objects inspired our third design. The current version of the system assumes that: (1) users are in an immersive virtual environment (IVE); (2) users are past the query phase of the IR task; and (3) users are using hand-centered controls (e.g., tracked handheld controllers). We plan to also address interface choices (e.g., pagination vs. exhaustive streams) and post-triage IR tasks (e.g., comparing information sources) in future versions of our system.

6 CONCLUSION

In this paper, we introduced a system for evaluating different interaction types and information layouts in a virtual reality SERP. Our current implementation focuses on triaging information tasks on a SERP with interaction type (menu, swipe, place) and information layouts (1, 2, or 3 columns) as our study variables. This system will provide a rich set of interaction data, in addition to qualitative questionnaire data, for our upcoming user studies. We are excited that this system enables taking early steps towards a more comprehensive understanding of interactions in the context of information retrieval in immersive virtual spaces.

[1] https://assetstore.unity.com/packages/tools/gui/vr-ui-kit-material-design-system-135769
[2] https://assetstore.unity.com/packages/tools/animation/dotween-hotween-v2-27676

REFERENCES

[1] 2021. Oculus Rift Store: VR Games, Apps, & More. (2021). https://www.oculus.com/experiences/rift/?locale=en_US Accessed on 03.09.2021.

[2] 2021. PlayStation VR: Live the game in incredible virtual reality worlds. (2021). https://www.playstation.com/en-us/ps-vr/ Accessed on 03.09.2021.

[3] Ferran Argelaguet and Carlos Andujar. 2013. A survey of 3D object selection techniques for virtual environments. *Computers & Graphics* 37, 3 (2013), 121–136.

[4] Jaime Arguello and Anita Crescenzi. 2019. Using Principal Component Analysis to Better Understand Behavioral Measures and their Effects. In *Proceedings of the 2019 ACM SIGIR International Conference on Theory of Information Retrieval.* 177–184.

[5] Mark Billinghurst, Jerry Bowskill, Nick Dyer, and Jason Morphett. 1998. An evaluation of wearable information spaces. In *Proc. IEEE 1998 Virtual Reality Annual International Symposium.* IEEE, 20–27.

[6] Doug A Bowman, Donald B Johnson, and Larry F Hodges. 2001. Testbed evaluation of virtual environment interaction techniques. *Presence: Teleoperators & Virtual Environments* 10, 1 (2001), 75–95.

[7] Doug A. Bowman and Ryan P. McMahan. 2007. Virtual reality: How much immersion is enough? *Computer (Long. Beach. Calif).* 40, 7 (2007), 36–43. https://doi.org/10.1109/MC.2007.257

[8] Doug A Bowman, Chris North, Jian Chen, Nicholas F Polys, Pardha S Pyla, and Umur Yilmaz. 2003. Information-rich virtual environments: theory, tools, and research agenda. In *Proceedings of the ACM symposium on Virtual reality software and technology.* 81–90.

[9] John Brooke et al. 1996. SUS-A quick and dirty usability scale. *Usability evaluation in industry* 189, 194 (1996), 4–7.

[10] George Buchanan and Fernando Loizides. 2007. Investigating document triage on paper and electronic media. In *International Conference on Theory and Practice of Digital Libraries.* Springer, 416–427.

[11] Georg Buscher, Andreas Dengel, Ralf Biedert, and Ludger V Elst. 2012. Attentive documents: Eye tracking as implicit feedback for information retrieval and beyond. *ACM Transactions on Interactive Intelligent Systems (TiiS)* 1, 2 (2012), 1–30.

[12] Laura A Granka, Thorsten Joachims, and Geri Gay. 2004. Eye-tracking analysis of user behavior in WWW search. In *Proceedings of the 27th annual international ACM SIGIR conference on Research and development in information retrieval.* 478–479.

[13] Jacek Gwizdka. 2014. Characterizing relevance with eye-tracking measures. In *Proceedings of the 5th information interaction in context symposium.* 58–67.

[14] Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Human mental workload*, Peter A. Hancock and Najmedin Meshkati (Eds.). Advances in Psychology, Vol. 52. Elsevier Science Publishers B. V., North Holland, 138–183.

[15] Marti Hearst. 2009. *Search user interfaces.* Cambridge university press.

[16] Diogo Gil Vieira Henriques. 2014. LSpeakIt: Immersive interface for 3D object Search. *LSpeakIt: Immersive Interface for 3D Object Search* (2014).

[17] Kalervo Järvelin and Jaana Kekäläinen. 2002. Cumulated gain-based evaluation of IR techniques. *ACM Transactions on Information Systems (TOIS)* 20, 4 (2002), 422–446.

[18] Thorsten Joachims. 2002. Optimizing search engines using clickthrough data. In *Proceedings of the eighth ACM SIGKDD international conference on Knowledge discovery and data mining.* 133–142.

[19] Thorsten Joachims and Filip Radlinski. 2007. Search engines that learn from implicit feedback. *Computer* 40, 8 (2007), 34–40.

[20] Diane Kelly. 2009. *Methods for evaluating interactive information retrieval systems with users.* Now Publishers Inc.

[21] Diane Kelly and Nicholas J Belkin. 2001. Reading time, scrolling and interaction: exploring implicit sources of user preferences for relevance feedback. In *Proceedings of the 24th annual international ACM SIGIR conference on Research and development in information retrieval.* 408–409.

[22] Diane Kelly and Cassidy R Sugimoto. 2013. A systematic review of interactive information retrieval evaluation studies, 1967–2006. *Journal of the American Society for Information Science and Technology* 64, 4 (2013), 745–770.

[23] Eric Krokos, Catherine Plaisant, and Amitabh Varshney. 2019. Virtual memory palaces: immersion aids recall. *Virtual Reality* 23, 1 (2019), 1–15.

[24] Lik-Hang Lee and Pan Hui. 2018. Interaction methods for smart glasses: A survey. *IEEE access* 6 (2018), 28712–28732.

[25] Sebastian Marwecki, Maximilian Brehm, Lukas Wagner, Lung-Pan Cheng, Florian'Floyd' Mueller, and Patrick Baudisch. 2018. Virtualspace-overloading physical space with multiple virtual reality users. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems.* 1–10.

[26] Randy Pausch, Dennis Proffitt, and G. Williams. 1997. Quantifying immersion in virtual reality. In *Proc. Conf. Comp. Graphics and Interactive Techniques.* 13–18.

[27] Maurice Schleußinger. 2021. Information retrieval interfaces in virtual reality—A scoping review focused on current generation technology. *Plos one* 16, 2 (2021), e0246398.

[28] Milad Shokouhi and Qi Guo. 2015. From queries to cards: Re-ranking proactive card recommendations based on reactive search history. In *Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval.* 695–704.

[29] Unity Technologies. 2021. AR and VR Games. (2021). https://unity.com/solutions/ar-and-vr-games Accessed on 03.09.2021.

[30] Austin R Ward and Rob Capra. 2020. Immersive Search: Using Virtual Reality to Examine How a Third Dimension Impacts the Searching Process. In *Proceedings of the 43rd International ACM SIGIR Conference on Research and Development in Information Retrieval.* 1621–1624.

[31] Max L Wilson. 2011. Search user interface design. *Synthesis lectures on information concepts, retrieval, and services* 3, 3 (2011), 1–143.

[32] Andrew Jie Zhou and Grace Hui Yang. 2018. Minority Report by Lemur: Supporting Search Engine with Virtual Reality. In *The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval.* 1329–1332.