User-Centered Protoyping for Single-User Cross-Reality Virtual Object Transitions

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Figure 1: Single-user CR prototype for reservoir engineering data visualization. The user performing analytical work on a laptop transit 3D reservoir model from standard monitor to VR space to increase working space and improve spatial perception.

Abstract

Cross-reality is a newly emerged research field that studies the transition and current usage of multiple systems along Milgram's Reality-Virtuality Continuum(RVC). Our research currently focuses on studying how the user could interact with CR applications and move virtual objects along Milgram's RVC. The prototype is an embodiment of an application and can be used to gain insights and knowledge. We build low-fidelity and high-fidelity prototypes to study the transition of 3D virtual objects. However, We face challenges since cross-reality involves more than one space on the RVC, so when designing the prototype, researchers and designers can not refer to their previous experience and interaction metaphor from a space they are familiar with, such as physical, AR, or VR space. Thus we plan to conduct elicitation studies to gain more knowledge and insights to serve as a benchmark to guide the design of the prototypes.

Index Terms: Human-centered computing—Interaction design—Interaction design process and methods—User centered design Human-centered computing—Mixed / augmented reality Human-centered computing—Virtual reality

1 Introduction

Researchers have spent decades conducting studies and designing applications to exploit the benefits and define the limits of Extended Reality (XR) on different points along Milgram's RV continuum (RVC) [23].

The conventional visual output device, such as the standard monitor, utilizes a 2D array of pixels to represent information or visualization and does not give the user the illusion that the computer-generated content exists in the same space as the user, which is prove to be more suitable for tasks that require accurate and precise viewing [17, 27, 35].

Immersive visual output devices such as virtual reality (VR) head-mounted displays (HMDs) or augmented reality(AR) HMDs are expected to increase performance for tasks that involve 3D visualizations as they support stereopsis, head tracking, body motion tracking, and provide depth cues that are not available with a standard monitor [8, 16]. These advantages can lead to better spatial understanding and enhanced data navigation. In addition, human eyes have a wide field of view (FoV) and a high dynamic range [38]. The wide FoV provided by VR HMDs allows the user to be fully immersed in the virtual environment and reduces the clutter of information and UI elements [8]. However, the wide FoV leads to low-resolution density which could potentially be solved with high cost devices and increased data transport rates. Moreover, vergence-accommodation conflict (VAC) is another issue with VR HMDs that causes eye strain and visual fatigue [39]. Furthermore, VR HMDs isolate the user from the real physical environment, so the user only perceives information from virtual content rendered on the VR display.

AR HMDs allow the user to perceive information from the physical world while preserving functionality such as stereoscopic visualization and body motion tracking. Nevertheless, a narrow FoV and low ambient contrast ratio (ACR) of current HMDs are still barriers between the user and a fully immersive experience [7, 21, 32, 39].

Figure 2: A user views 2D charts on a standard monitor while interacting with 3D graphs in AR space [31].

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With the advancement in head-mounted displays (HMDs), multi-sensory rendering, computational capability, and enhanced networking technologies, spaces along RVC can be connected. Researchers have started conducting studies and developing applications that involve the transition between or concurrent usage of multiple systems on the RVC [3, 22, 29]. Although multi-user CR has been at the forefront of the CR research agenda, the potential benefits brought by single-user CR should not be neglected. Our work aims to develop single-user CR applications that bridge different points of RVC to integrate the advantages and overcome the limitations. Currently, we are focusing on building prototypes that support the transition of 3D virtual objects along RVC, a scenario in the single-user CR design space proposed by Wang et al. derived from the definition of CR [37]. Our goal is to gain more insights to develop guidelines that contribute to user-centered single-user CR applications that support the transition of virtual objects between commercially available visual output devices, including desktops, laptops, VR HMDs, and AR HMDs. Thus the user could move the virtual object to the space along the RVC that is most suitable for working with it, which enhances the user experience with immersive technology. The following section describes a major challenge we face when designing a CR prototype and our idea for overcoming the challenge.

2 Transition of Virtual Objects

Studies have found that prototyping can contribute to aiding the learning of a concept and helping to communicate an idea [14]. This section will discuss the challenge associated with our prototyping process and the study needed to aid prototyping. The challenge and solution are based on our personal opinions and anecdotal feedback from reservoir engineers.

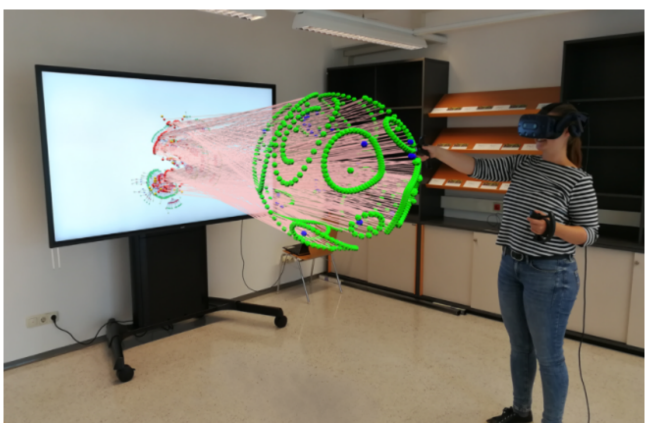

Figure 3: Prototype presented by Schwajda that support transition of graph-based data from a standard monitor to AR space [30]

2.1 Prototyping Challenge

Our Single-user CR prototype aims to allow users to move 3D virtual objects to environments with different degrees of virtuality. Such a transition is useful since some tasks are more productive with standard monitors and conventional input methods like mouse and keyboard while other benefit from extended reality (XR). In addition, working with XR devices on a daily basis leads to negative impacts on the user that cause body and mental fatigue [6]. On the other hand, tasks such as analyzing 3D visualization may be more efficiently done in a VR or AR environment. Cartwright et al. point out that the transition of virtual objects can enhance reservoir engineering workflow [11]. However, to enhance the user experience with a CR virtual object transition session, the seamless transition needs to be triggered and executed by an effortless and intuitive interaction [36].

The prototype we build is part of a project that studies how to use immersive technology to enhance reservoir engineering workflows(Figure1). We aim to allow reservoir engineers to move 3D reservoir models from a standard monitor to an immersive space when needed and back. In order to maintain a relatively high framerate that was suggested by a previous study, we attached VR HMD to gain more computing power [41]. We started with creating low-fidelity (lo-fi) prototypes since those are quick and easy to draw. One of the low-fi prototypes utilizes a similar interaction to initiate and complete the transition of virtual objects as the prototype presented by Schwajda et al. Schwajda et al. present a fully functioned prototype that allows the user who wears AR HMDs to transit graph-based data from a standard monitor to an AR space using "grab" and "pull" hand gestures [30] (Figure2). This is an example of a possible interaction that virtual transit objects from one space to another along RVC since hand gestures are one of the most popular input modalities associated with AR HMDs [26]. When implementing the high-fi prototype, a problem we face is that the VR HMDs we use in the project, such as Oculus Quest 2 and HTC VIVE, do not support high-quality video pass-through functionality. Thus the reservoir engineers that wear those HMDs can not see the virtual content displayed on the standard monitor through the camera of the HMDs. As a consequence, they can not select and move the 3D virtual object from the monitor to the VR space. Some engineers also suggested that a virtual button could be added to the monitor so that they could select the 3D virtual object and move it to VR space using a mouse and keyboard. This problem leads to a research question that we want to investigate: How would users prefer to move 3D virtual objects from a standard monitor to 3D space and back during a CR session. Till now, no evidence has been collected on what input modality and interaction is most intuitive and preferred by the user.

2.2 Input Modality

Different visual output systems along the RVC have different input modalities and interactions that are most commonly implemented. Users usually interact with standard monitor devices using the mouse, keyboard, multi-touch display, and digital pen [4, 10, 28]. The controller with joysticks, buttons, touchpad, and support motion tracking is widely used to interact with VR HMDs [2]. Hand gesture interaction enabled by an optical hand tracker is the most common input modality for AR HMDs. However, VR headsets such as Oculus Quest 2 also support hand gesture interaction. The user could interact with other VR headsets or even standard monitor devices by attaching an external device such as the Leap Motion controller [4, 9]. The data glove is another type of input device that supports hand gesture interaction with standard monitor devices, VR HMDs and AR HMDs [18, 19, 40]. Researchers and developers have also been exploring other input modalities that could potentially interact with systems in different spaces on RVC, such as voice input and eye-gaze [2, 4, 15, 32].

When the user is working with a CR prototype that supports virtual object transition, the user will interact with devices that belong to at least two spaces along the RVC. An important design decision is to choose the main input modalities for the CR system. The developer could utilize different input modalities that are proven to be most suitable for systems in different spaces on the RVC, such as mouse and keyboard for standard monitor devices. However, a potential drawback is that a user might be distracted from the task when frequently switching back between different input modalities with the CR transition. Another developing choice is to unify the way of interaction for multiple systems along RVC so that the user always sticks with one type of input modality. However, a trade-off with this implementation is that the user may need to adapt to input modalities that are not commonly associated with a particular space on the RVC. For example, hand gesture interaction is the most commonly utilized way of interaction for AR HMDs [26]. Meanwhile, hand gesture interaction is less frequently associated with desktops and other standard monitor devices than mice and keyboards. To enforce users interacting with the system using a less common input modality may create frustration and fatigue, which could cause increases in the task load and decreases in productivity. Case studies need to be conducted to determine which approach is more suitable for a specific task. With the second implementation, the interaction that initiates and completes the transition of virtual objects is associated with the input modality. Nevertheless, if the developer and researcher choose to utilize multiple input modalities for systems across the RVC, the interaction that is more effortless and comfortable to the user that triggers and executes the transition is yet to be determined. Researchers and developers may utilize the input modality most commonly implemented in a space on the RVC to trigger the transition of the virtual object between that space to another due to the easiness of implementation and other practical reasons. However, this may sacrifice usability and reduce user experience.

2.3 User Elicitation

When interacting with a system along RVC, the user tends to get the reference from previous experience with a similar system [1, 12]. Thus researchers and developers can implement interaction using the same way as those have been proven to be efficient and preferred by the user. However, single-user CR virtual object transition is an unexplored interaction space. Thus there is no established interaction that the user can refer to trigger such a transition. In addition, previous elicitation studies point out that researchers and developers often do not share the same conceptual models as the user prefers [25]. Elicitation studies are conducted to gain insights that contribute to the design of user-centered applications, among which there are many studies on how the user wants to interact with a system [1,5,12, 13, 20]. Elicitation studies can gain insight into how the user wants to move the virtual object from one reality to another. Researchers may use wizard-of-oz approaches in user elicitation studies so that the user has the illusion of having full control of the virtual object transition while the researchers control the transition [5, 13, 20]. Quantitative data such as agreement measures, user preference count, and the number of occurrences can be used to analyze elicited data and find consensus among users on the set of interactions that should be implemented for the virtual object transition [1, 24, 33, 34]. Our goal is to find out what input modality and interaction the user wants to use without the limitation of the current software, hardware, and difficulty of implementation.

3 Conclusion

In this position paper, we discuss the design decision and challenges of interactions to trigger single-user CR virtual object transition in a CR prototype. In order to gain more insights that contribute to a guideline for developing single-user CR prototypes, we will conduct elicitation studies that investigate the way of interaction the user wants to move the virtual object between spaces across the RVC.

References

[1] L. Angelini, F. Carrino, S. Carrino, M. Caon, O. A. Khaled, J. Baumgartner, A. Sonderegger, D. Lalanne, and E. Mugellini. Gesturing on the steering wheel: A user-elicited taxonomy. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, AutomotiveUI '14, p. 1–8. Association for Computing Machinery, New York, NY, USA, 2014. doi: 10.1145/2667317.2667414

[2] C. Anthes, R. J. García-Hernández, M. Wiedemann, and D. Kranzlmüller. State of the art of virtual reality technology. In *2016 IEEE Aerospace Conference*, pp. 1–19, 2016. doi: 10.1109/AERO.2016.7500674

[3] J. Auda, U. Gruenefeld, and S. Mayer. It takes two to tango: Conflicts between users on the reality-virtuality continuum and their bystanders. In *Proceedings of the 1st ACM International Workshop on Cross-Reality Interaction*. ACM, 2020.

[4] D. Bachmann, F. Weichert, and G. Rinkenauer. Review of three-dimensional human-computer interaction with focus on the leap motion controller. *Sensors*, 18(7), 2018. doi: 10.3390/s18072194

[5] C. Beşevli, O. T. Buruk, M. Erkaya, and O. Özcan. Investigating the effects of legacy bias: User elicited gestures from the end users perspective. DIS '18 Companion, p. 277–281. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3197391.3205449

[6] V. Biener, S. Kalamkar, N. Nouri, E. Ofek, M. Pahud, J. J. Dudley, J. Hu, P. O. Kristensson, M. Weerasinghe, K. Pucihar, M. Kljun, S. Streuber, and J. Grubert. Quantifying the effects of working in vr for one week, 2022. doi: 10.48550/ARXIV.2206.03189

[7] M. Billinghurst, A. Clark, and G. Lee. A survey of augmented reality. *Foundations and Trends® in Human–Computer Interaction*, 8(2-3):73–272, 2015. doi: 10.1561/1100000049

[8] D. A. Bowman and R. P. McMahan. Virtual reality: How much immersion is enough? *Computer*, 40(7):36–43, 2007. doi: 10.1109/MC.2007.257

[9] D. A. Bowman, C. A. Wingrave, J. M. Campbell, V. Q. Ly, and C. J. Rhoton. Novel uses of pinch gloves™ for virtual environment interaction techniques. *Virtual Reality*, 6:122–129, 2002.

[10] N. C. Camgöz, A. A. Kindiroglu, and L. Akarun. Gesture recognition using template based random forest classifiers. In L. Agapito, M. M. Bronstein, and C. Rother, eds., *Computer Vision - ECCV 2014 Workshops*, pp. 579–594. Springer International Publishing, Cham, 2015.

[11] S. Cartwright, S. Samoil, B. Lawton, D. Hu, S. Xie, E. Wang, A. Aminbeidokhti, S. Dawar, R. Dalton, P. Daeijavad, F. Maurer, and Z. Chen. Enhancing Reservoir Engineering Workflows with Augmented and Virtual Reality. vol. Day 1 Wed, March 16, 2022 of *SPE Canadian Energy Technology Conference*, 03 2022. D011S003R002. doi: 10.2118/208880-MS

[12] E. Chan, T. Seyed, W. Stuerzlinger, X.-D. Yang, and F. Maurer. User elicitation on single-hand microgestures. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, p. 3403–3414. Association for Computing Machinery, New York, NY, USA, 2016. doi: 10.1145/2858036.2858589

[13] S. Chopra and F. Maurer. *Evaluating User Preferences for Augmented Reality Interactions with the Internet of Things*. Association for Computing Machinery, New York, NY, USA, 2020.

[14] E. R. Coutts, A. Wodehouse, and J. Robertson. A comparison of contemporary prototyping methods. *Proceedings of the Design Society: International Conference on Engineering Design*, 1(1):1313–1322, 2019. doi: 10.1017/dsi.2019.137

[15] A. Fonnet and Y. Prié. Survey of immersive analytics. *IEEE Transactions on Visualization and Computer Graphics*, 27(3):2101–2122, 2021. doi: 10.1109/TVCG.2019.2929033

[16] K. Gruchalla. Immersive well-path editing: investigating the added value of immersion. In *IEEE Virtual Reality 2004*, pp. 157–164, 2004. doi: 10.1109/VR.2004.1310069

[17] I. D. Haskell and C. D. Wickens. Two- and three-dimensional displays for aviation: A theoretical and empirical comparison. *The International Journal of Aviation Psychology*, 3(2):87–109, 1993. doi: 10.1207/s15327108ijap0302_1

[18] B. N. Z. K. L. J. K. I. K. S. G. S. Ku J, Mraz R. A data glove with tactile feedback for fmri of virtual reality experiments. In *CyberPsychology Behavior*. Oct. 2003.

[19] P. Kumar, S. S. Rautaray, and A. Agrawal. Hand data glove: A new generation real-time mouse for human-computer interaction. In *2012 1st International Conference on Recent Advances in Information Technology (RAIT)*, pp. 750–755, 2012. doi: 10.1109/RAIT.2012.6194548

[20] S.-S. Lee, J. Chae, H. Kim, Y.-k. Lim, and K.-p. Lee. Towards more nat-

ural digital content manipulation via user freehand gestural interaction in a living room. UbiComp '13, p. 617–626. Association for Computing Machinery, New York, NY, USA, 2013. doi: 10.1145/2493432.2493480

[21] Y.-H. LEE, T. ZHAN, and S.-T. WU. Prospects and challenges in augmented reality displays. *Virtual Reality Intelligent Hardware*, 1(1):10–20, 2019. doi: 10.3724/SP.J.2096-5796.2018.0009

[22] J. Mayer, S. Auer, J. Friedl, and C. Anthes. Volumetric data interaction in ar and vr using a handheld touch-sensitive device. In H.-C. Jetter, J.-H. Schröder, J. Gugenheimer, M. Billinghurst, C. Anthes, M. Khamis, and T. Feuchtner, eds., *ISS'21 Workshop Proceedings: "Transitional Interfaces in Mixed and Cross-Reality: A new frontier?"*, 2021. doi: 10.18148/kops/352-2-1qsz0ws7eufba2

[23] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino. Augmented reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*, 2351, January 1994. doi: 10.1117/12.197321

[24] M. R. Morris. Web on the wall: Insights from a multimodal interaction elicitation study. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces*, ITS '12, p. 95–104. Association for Computing Machinery, New York, NY, USA, 2012. doi: 10.1145/2396636.2396651

[25] M. Nielsen, M. Störring, T. B. Moeslund, and E. Granum. A procedure for developing intuitive and ergonomic gesture interfaces for hci. In A. Camurri and G. Volpe, eds., *Gesture-Based Communication in Human-Computer Interaction*, pp. 409–420. Springer Berlin Heidelberg, Berlin, Heidelberg, 2004.

[26] S. S. M. Nizam, R. Z. Abidin, N. C. Hashim, M. C. Lam, H. Arshad, and N. A. A. Majid. A review of multimodal interaction technique in augmented reality environment. *International Journal on Advanced Science, Engineering and Information Technology*, 8(4-2):1460–1469, 2018. doi: 10.18517/ijaseit.8.4-2.6824

[27] A. Riegler, C. Anthes, H.-C. Jetter, C. Heinzl, C. Holzmann, H. Jodlbauer, M. Brunner, S. Auer, J. Friedl, B. Fröhler, C. Leitner, F. Pointecker, D. Schwajda, and S. Tripathi. Cross-virtuality visualization, interaction and collaboration. In *Proceedings of the 1st ACM International Workshop on Cross-Reality Interaction*. ACM, 2020.

[28] M. J. Schedlbauer. A survey of manual input devices. Technical report, Citeseer, 2007.

[29] D. Schwajda and C. Anthes. Utilizing f-formations in collaborative cross-virtuality analytics scenarios. In *AVI'22 Workshop Proceedings: "ENHANCING CROSS-REALITY APPLICATIONS AND USER EXPERIENCES"*, 2022.

[30] D. Schwajda, F. Pointecker, L. Böss, and C. Anthes. Transforming graph-based data visualisations from planar displays into augmented reality 3d space. In H.-C. Jetter, J.-H. Schröder, J. Gugenheimer, M. Billinghurst, C. Anthes, M. Khamis, and T. Feuchtner, eds., *ISS'21 Workshop Proceedings: "Transitional Interfaces in Mixed and Cross-Reality: A new frontier?"*, 2021. doi: 10.18148/kops/352-2-1kugqssauin8a2

[31] A. Shepard. Immersion analytics wins 1st place in tableau competition by creating breakthrough immersive visualizations, June 2021.

[32] I. Sicaru, C. Ciocianu, and C.-A. Boiangiu. A survey on augmented reality. 12 2017.

[33] R.-D. Vatavu and J. O. Wobbrock. Formalizing agreement analysis for elicitation studies: New measures, significance test, and toolkit. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, CHI '15, p. 1325–1334. Association for Computing Machinery, New York, NY, USA, 2015. doi: 10.1145/2702123.2702223

[34] R.-D. Vatavu and J. O. Wobbrock. Between-subjects elicitation studies: Formalization and tool support. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, p. 3390–3402. Association for Computing Machinery, New York, NY, USA, 2016. doi: 10.1145/2858036.2858228

[35] N. Wang, A. Aminbeidokhti, and F. Maurer. Individual and collaborative cross-reality immersive analytics - initial ideas. In *Proceedings of the 1st ACM International Workshop on Cross-Reality Interaction*. ACM, 2020.

[36] N. Wang and F. Maurer. Challenges of single-user cross reality applications. In *AVI'22 Workshop Proceedings: "ENHANCING CROSS-REALITY APPLICATIONS AND USER EXPERIENCES"*, 2022.

[37] N. Wang and F. Maurer. A design space for single-user cross-reality applications. In *Proceedings of the 2022 International Conference on Advanced Visual Interfaces*, AVI 2022. Association for Computing Machinery, New York, NY, USA, 2022. doi: 10.1145/3531073.3531116

[38] J. Xiong and S.-T. Wu. Planar liquid crystal polarization optics for augmented reality and virtual reality: from fundamentals to applications. *fundamentals to applications*, 1, 02 2021. doi: 10.1186/s43593-021-00003-x

[39] T. Zhan, K. Yin, J. Xiong, Z. He, and S.-T. Wu. Augmented reality and virtual reality displays: Perspectives and challenges. *iScience*, 23(8):101397, 2020. doi: 10.1016/j.isci.2020.101397

[40] D. Zhang, Y. Shen, S. Ong, and A. Nee. An affordable augmented reality based rehabilitation system for hand motions. In *2010 International Conference on Cyberworlds*, pp. 346–353, 2010. doi: 10.1109/CW.2010.31

[41] D. J. Zielinski, H. Rao, N. Potter, L. G. Appelbaum, and R. Kopper. Evaluating the effects of image persistence on dynamic target acquisition in low frame rate virtual environments. In *2016 IEEE Virtual Reality (VR)*, pp. 319–320, 2016. doi: 10.1109/VR.2016.7504782