Balancing Realities by Improving Cross-Reality Interactions

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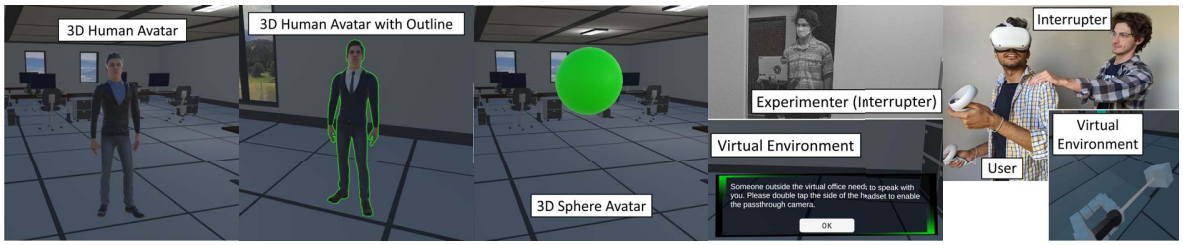

(a) FDA (b) PDA (c) NDA (d) UIP (e) Baseline

Figure 1: The five experimental conditions in my first cross-reality interruptions experiment: (a) fully diegetic avatar, (b) partially diegetic avatar, (c) non-diegetic avatar, (d) user interface with passthrough camera view, and (e) non-mediated baseline interaction (tapping on one's shoulder without a visual representation).

Abstract

Virtual reality (VR) devices have a demonstrated capability to make users feel present in a virtual world. Research has shown that, at times, users desire a less immersive system that provides them awareness of and the ability to interact with elements from the real world and with a variety of devices. Understanding such cross-reality interactions is an under-explored research area that will become increasingly important as immersive devices become more ubiquitous. In this extended abstract, I provide an overview of my previous PhD research on facilitating cross-reality interactions between VR users and nearby non-VR interrupters. I discuss planned future research to investigate the social norms that are complicated by these interactions and design solutions that lead to meaningful interactions. These topics and questions will be discussed at the IEEE VR 2022 Doctoral Consortium.

Index Terms: Human-centered computing—Human computer interaction (HCI)—HCI design and evaluation methods—User studies Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality

1 Introduction

Virtual reality (VR) devices immerse users in a virtual world, but users still occupy a physical space that at times requires their awareness or interaction. VR users therefore experience a reality balancing predicament: their body exists in a physical reality, but they are cognitively, behaviorally, and often socially engaged in a virtual reality. For example, a VR user may be embodied in an avatar in a virtual meeting but need to talk to someone in their real surroundings. Such cross-reality interactions (e.g., between the VR user and the real-world person, and between the VR user and other virtual meeting participants) are complicated by modern VR system designs that isolate users from their real environment and do not share information about users' real environment with people in the virtual one.

For short uses this might not present a problem, but as VR systems are used by more people, for more purposes, and for longer durations, facilitating interactions across realities will become increasingly important. To inform how we interact with others, humans develop a *theory of mind*, or attribute mental states to themselves and others [1]. This ability is limited when people cannot interpret the gaze of another person, such as when the other person is wearing a VR head-mounted display (HMD) or represented as an avatar. This is particularly troublesome for cross-reality interpersonal interruptions. In the real world we use our extensive and dynamic sense of shared awareness, context, and established social norms to manage interruptions. For example, when interrupting a computer user, the interrupter will commonly assess how busy the user is and then subtly communicate their intention to interrupt by approaching the user or gesturing. When interrupting someone using a VR system, however, interrupters typically have none of these assessment abilities or interruption norms. They cannot see what the VR user is looking at or interacting with, and they do not have a subtle way to announce their intention to interrupt. The effects can result in confusion, miscommunication, or even harm to relationships as a result of apparent violations of social norms. A more holistic VR design would allow users to better balance their realities, e.g., with seamless transitions and/or intuitive blending between real and virtual content.

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2 Related Work

Milgram & Kishino's Reality-Virtuality (RV) continuum historically has been useful for classifying systems that mix real and virtual content (i.e., XR systems) [5]. In modern VR, however, the virtual cannot fully replace the real, and so the RV continuum is discontinuous [7]. While Milgram's RV continuum is useful for classifying an extended reality (XR) application's initial state, the application's position on the continuum may be dynamic throughout the experience. Additionally, at any given moment, a VR user may be mentally present or socially engaged somewhere on the continuum that does not match the application's own RV position. Terzimehić et al. examined people's perceptions of their presence in the real world, the digital world (defined by ubiquitous technology), or mental world (i.e., within their thoughts). They found a person's presence regularly shifts among these worlds, which motivates exploring how to balance or smooth such transitions [8].

Researchers have explored numerous methods for transitioning and interacting across the RV continuum [2]. Various consumer VR HMDs have features that allow users to incorporate elements of the real environment inside the HMD, e.g., passthrough views that enable real-time video of users' physical surroundings and messaging systems that link to users' mobile phones or social media. However, there are several open research questions about how effectively these designs support balancing users' realities.

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3 Prior PhD Research

My work so far has focused on cross-reality interruptions between a real-world person (i.e., someone not immersed in VR) and a VR user as one mode of cross-reality interactions. In a paper published at IEEE ISMAR 2021 [4], I investigated how different representations of real-world interrupters inside a virtual environment (VE) affect the VR user's experience and co-presence with the interrupter. I designed three representations with varying degrees of *diegesis*, or degrees to which the interrupter representation was consistent with the rest of the virtual experience (see Fig. 1). I compared these avatars to the contemporary industry standard of using the passthrough camera mode to view the interrupter and to the baseline condition of VR users having to take off their headset to interact with an interrupter. Based on related work in VR interruptions [3, 6], I hypothesized that the fully diegetic avatar would give users the highest sustained presence in the VE and best interaction experience. The within-subjects user study ($N = 24$) involved participants completing simple block-stacking tasks in VR and being interrupted in each of the forms show in Fig. 1. The diegetic avatars provided the highest continuous sense of place illusion measured before, during, and after the interruption. Additionally, the diegetic avatars scored the highest for quality of interaction and gave participants reasonably high senses of co-presence with the interrupter. Interestingly, several participants noted that the green outline around the partially diegetic avatar made it seem *more human* than the fully diegetic avatar because it differentiated it from the VE.

In conducting that user study, I realized interacting with someone wearing a headset is quite different from usual face-to-face interactions, so I have begun examining these cross-reality interactions from the interrupter's perspective. I ran a pilot study ($N = 10$) to investigate how cues about the VR user's virtual activities and a gesture-based interruption interface affect the interrupter's experience interacting with a VR user. To test these ideas, I constructed a Wizard-of-Oz prototype comprised of LED lights and a Gravity Gesture & Touch Sensor [1] driven by an Arduino Uno microcontroller and mounted it to an Oculus Quest 2 VR HMD. Participants were told the LED lights display the VR user's virtual activity level by coloring them red for high activity, yellow for medium activity, and green for low activity (See Fig. 2). Additionally, participants were instructed to use an interruption interface which allowed them to initiate an interruption by making a wave gesture in front of the HMD. The study design included timing how long it took participants to initiate an interruption, subjective questionnaire data about their interruption experience and perception of the person they interrupt, and qualitative semi-structured interview data. The results of the pilot study did not show significant effects of the use of the *Gesture System* on participants' interruption experience, but it was described as an interesting and useful interface. The *Virtual Activity Cues* showed significant benefits for participants' interruption experience and perception of interruptee. In the qualitative analysis, an emergent theme was a desire for the interruption system to facilitate the theory of mind [1] cues obstructed by the VR HMD.

4 Planned Future Work

Based on the findings of the pilot study, I will fine-tune the experimental design to isolate the factors that improve the interrupter's experience. Then, I will conduct a full user study with the goal of producing design guidelines for making VR devices that more holistically balance realities. Afterward, I plan to continue investigating cross-reality interactions and transitions more broadly. By their nature, interruptions are brief interactions. I am interested in the design of interfaces that support cross-reality interactions over longer durations and among a variety of devices (e.g., XR, mobile, desktop), each with different affordances. Some differences will be hardware-based, e.g., discrepancies in resolution and field of view. Other differences will be software-based, e.g., different perspectives, controls, and interfaces. It is important that these differences are reconciled when people interact across realities.

[1] https://www.dfrobot.com/product-1898.html

(a) Low: Green (b) Medium: Yellow (c) High: Red

Figure 2: Cues showing low, medium, and high activity levels.

At the IEEE VR 2022 Doctoral Consortium, I will discuss these ideas with both my peers and established researchers in the field. The following questions may lead to interesting discussions that will help shape the direction of my dissertation.

RQ1 What social cues and norms are complicated by XR devices and cross-reality contexts? Which of these complications will be resolved by people becoming more familiar with the technology, and which require a design intervention?

RQ2 How does VR complicate users' typical transitions between real and digital realities? How can VR systems be designed to facilitate users balancing realities?

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