On Intent Inclusivity in Spontaneous Cross Realities

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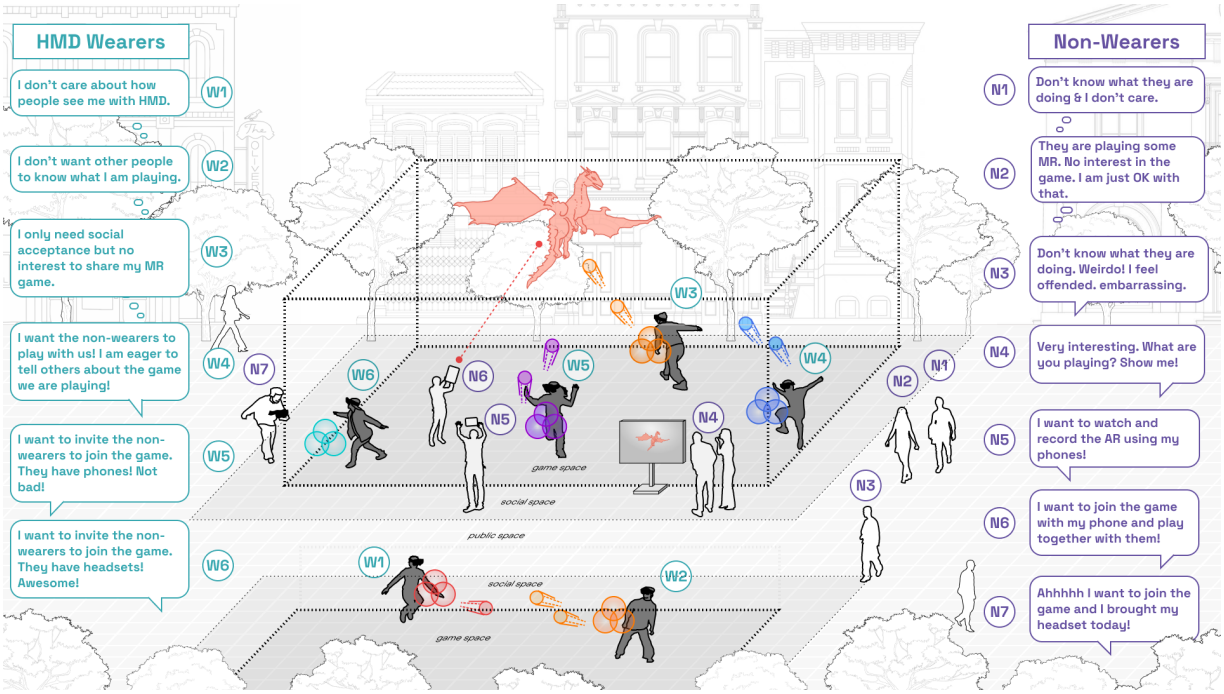

Figure 1: The illustration showcases diverse intents between head-mounted display (HMD) wearers and non-wearers in spontaneous cross-reality scenarios, such as a public urban park. These varied situations emerge when HMD users and non-HMD users encounter each other in public spaces, each bringing different intents — to collaborate, spectate, or avoid interaction.

Abstract

As see-through Head-Mounted Displays (HMDs) become more prevalent, HMD wearers will start to encounter each other, as well as non-wearers, spontaneously in real-world settings. This is a typical cross reality (CR) scenario, where users are situated at the different points of the Reality-Virtuality Continuum. This situation introduces new complexities in social interactions. The central challenge is the inherent asymmetry of CR experiences: while see-through technology allows wearers to share the same physical environment, each has their own reality — the augmented layers they perceive are unique to each individual. It is unclear how people share their virtual, augmented, or actual realities. While multi-user cross reality applications have gained prominence in literature, including studies on cross reality between handheld devices and headsets as well as bystander inclusion, most research assumes an ideal scenario where all participants intend to collaborate using the same application. This scenario may be uncommon in the future, as individuals might have diverse intents — to collaborate, observe, or even avoid interaction with other individuals. This short paper uses the open-source spontaneous collocated mixed reality game probe, Multiplayer Omnipresent Fighting Arena (MOFA), reporting in-the-wild study observations from various real-world scenarios. Our goal is to explore various intents emerging in Spontaneous Cross Reality (SCR). We aim to inspire CR researchers to examine the technical, social, and ethical implications, identify key research questions, and envision intent-inclusive futures for SCR.

Index Terms: Virtual Reality, Augmented Reality, Mixed Reality, Cross Reality, Spontaneous Cross Reality, Intent Inclusivity

1 Introduction

In recent years, the proliferation of see-through head-mounted display (HMD) devices, such as Vision Pro [1] or Meta Quest 3 [21], has increased their prevalence in the consumer market. The increasing prominence of HMDs suggests a future where they could be as ubiquitous as smartphones. Thanks to video and optical see-through technology [16], an HMD wearer can see their surroundings and move around freely, expanding usage scenarios from private, controlled environments to public, spontaneous settings [20, 2]. As the HMDs become more commonplace, we are entering an era where HMD wearers will frequently encounter each other and non-wearers in everyday settings, spontaneously without any shared intents or common goals. This scenario introduces a new paradigm in social interactions, which we term Spontaneous Cross Reality (SCR).

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Introducing headsets into public and social spaces creates complex social challenges. The first challenge is the inherent power imbalance between HMD wearers and non-HMD wearers [22, 6, 4, 25], which impacts social acceptance, privacy, and the safety of non-wearers [5, 22, 7]. The second challenge is the inherent asymmetry of CR experiences. While see-through technology allows wearers to share the same physical environment, the augmented layers they perceive are unique to each individual by default. However, the study of collaborative collocated mixed reality often presumes that all wearers are perceiving the same layer — a situation that may not be common in the future, where HMD wearers will run their own apps by default. Spontaneous encounters between users with different intents and applications will become common. This leads us to our primary research question: *How do intents differ among various individuals present in an SCR environment, including players (HMD wearers), bystanders, and passersby?*

This question is crucial as it addresses the complex interplay of motivations, goals, and expectations that arise in SCR settings. Understanding these diverse intents is key to designing inclusive and effective SCR experiences. To investigate the question, we utilize an open-source spontaneous mixed reality game probe called Multiplayer Omnipresent Fighting Arena (MOFA) [15]. Through this probe, we observed users in field studies across various social settings to examine the technical, social, and ethical implications of SCR, and envision strategic futures for this emerging field.

By exploring the nuances of intent inclusivity in SCR, our work aims to lay the groundwork for more harmonious and effective integration of CR technologies into everyday social contexts. We believe that understanding and designing for diverse intents will be crucial in realizing the full potential of SCR while mitigating potential social and ethical challenges. Our study makes the following contributions: (1) we discuss the cross-device and cross-user categorizations, showing the intrinsic characteristics of spontaneous cross reality; (2) we provide empirical insights into the diverse intents that emerge in SCR environments, considering perspectives from HMD wearers, bystanders, and passersby.

2 Related Work

The field of Cross Reality (CR) has seen significant growth in recent years, with research spanning various aspects of multi-user Mixed Reality (MR) interactions. This section provides an overview of relevant studies and identifies the gap our work aims to address.

Multi-user MR Collaboration Several surveys have explored collaborative Mixed Reality environments [9, 3, 2, 23]. For example, Schroder et al. [24] explores dyadic collaboration in transitional interfaces that enable users to move between different realities. These works, while groundbreaking, primarily focus on predetermined collaborative scenarios.

Cross-device Interactions Research on cross-device interactions between handheld devices and headsets has also gained traction. For example, ShARe [17] enables co-located asymmetric multi-user interaction for AR HMDs by projecting content onto surfaces to include non-HMD users. MR-MEET [18] is a mixed reality collaborative interface that enables remote collaboration between HMD and handheld users. Their work highlighted the potential for seamless information flow across different form factors but did not address spontaneous encounters.

Bystander Inclusion The inclusion of non-HMD users, or bystanders, in MR experiences has been explored by researchers [2]. For example, Gugenheimer et al. [11] enables co-located experiences for virtual reality between HMD and non-HMD users. Eghbali et al. [8] further investigated the social acceptability of AR interactions in public spaces. Katins et al. [19] assesses user apprehensions about security, privacy, social implications, and trust in mixed reality technologies in the public. These studies underscored the importance of considering non-wearers in CR scenarios but do not fully address the spontaneous nature of future interactions.

Despite the rich body of work in CR and related fields, there is a notable absence of research specifically addressing *spontaneous* encounters between HMD users with different intents and applications. Most existing studies assume ideal conditions where all participants are using the same application with a shared goal. As HMDs become more pervasive, understanding and designing for spontaneous cross reality interactions will become increasingly crucial. Our work aims to bridge this gap by investigating the various intents that emerge in SCR environments, considering both wearer and non-wearer perspectives. By doing so, we hope to provide insights that will guide future research and development in this emerging field.

3 Methods

3.1 Apparatus

To investigate the emerging intents in SCR environments, we used a game probe, the Multiplayer Omnipresent Fighting Arena (MOFA)[1], to observe users' and bystanders' behaviours. MOFA is an open-source spontaneous mixed reality game that allows for dynamic interactions between HMD wearers and non-wearers in various social settings. It involves the use of the HoloKit X headset[2], an optical see-through headset based on an iPhone (for binocular display) and an Apple Watch (for hand-based interactions). Meanwhile, the bystanders can view the augmented content on a mobile device or a fixed display (see Figure 1). MOFA has been recognized as an award-winning game at ACM CHI 2023 Interactivity [14], IEEE ISMAR 2023 Demo [13], and SIGGRAPH 2024 Immersive Pavilion [15], demonstrating its reputation as a high-quality CR experience in the research community.

3.2 Study Scenarios

During 2022 to 2024, the team has monitored the use of the MOFA game in over 20 scenarios across different cities in the United State, Europe, and China. Hundreds of participants used and observed the game, covering a wide range of age groups and roles, including but not limited to game developers, researchers, artists, and students. The testing scenarios encompassed three types of distinct social settings, each captured a specific aspect of potential SCR interactions.

Urban Streets Representing busy environments, urban streets enabled us to study SCR interactions in fast-paced, crowded settings. The high foot traffic and mix of locals and tourists provided numerous opportunities for spontaneous encounters, while also allowing us to observe how users navigate real-world hazards in SCR contexts. For example, Figure 2 (left) depicts two players engaging in MOFA on the streets of SoHo in Manhattan, New York.

Indoor Pedestrian Areas These more structured, semi-private environments enabled us to observe SCR interactions in spaces where people engage in various activities (studying, socializing, attending classes). The indoor setting provided controlled conditions for CR experiences and allowed us to study more concentrated SCR interactions. For example, Figure 2 (middle) shows MOFA being played at the Oculus Transportation Hub in Manhattan, New York.

Public Parks These open, leisure-oriented spaces with diverse demographics allowed us to observe SCR interactions in relaxed, unstructured environments. The wide-open areas provided opportunities for diverse CR content placement and interactions between stationary and mobile individuals, both alone and in groups. For example, Figure 2 (right) shows the play of MOFA at the Dumbo park, Brooklyn, New York.

[1] https://mofa.ar
[2] https://holokit.io

Figure 2: Screenshots of the spectator view of MOFA, showing the use of the game in different in-the-wild scenarios. From left to right: urban streets; indoor pedestrian areas; public parks.

3.3 Procedure

The studies were conducted in-the-wild with voluntary participants. All participants were informed about the study's purpose and the functionality of MOFA, but were not given specific tasks or goals. They were informed of the data collection during the game. Each game session involves two participants wearing the device and several participants not wearing the device. During the game session, researchers observed and documented interactions, paying particular attention to the initiation of SCR interactions, the communication between wearers and non-wearers, the emergent behaviors and social norms, and the challenges and conflicts arising from asymmetric information access. After each session, participants were interviewed about their experiences, focusing on their intents, perceptions, and challenges encountered during SCR interactions.

3.4 Data Collection

We collected data through multiple channels, including field notes from researcher observations, audio recordings of post-session interviews, and video recordings of interactions (with consent and in public areas only). We used thematic analysis to identify recurring intent in field notes and interview transcripts, with a focus on emerging intents and interaction patterns in SCR.

4 Results and Discussions

4.1 Spontaneous Cross Reality

Spontaneous Cross-Reality (SCR) emerges when at least one participant, equipped with a HMD, is in close physical proximity to others, regardless of their device use. Central to SCR is its integration into both social and public spaces, grounded in the principles of *Proxemics of Human Territory* [12, 10]. In this context, social space is characterized as the sphere within which spontaneous social interactions occur among individuals, fostering a sense of community and shared experiences. In contrast, public space expands this domain to include those nearby but not directly involved in SCR activities, such as passersby and potential observers, thereby broadening the SCR experience's reach into the wider public arena. Distinct from traditional CR setups, SCR is defined by its spontaneity, emerging without the need for preset setups or schedules. This spontaneity ensures that each SCR encounter is quick and temporary, influenced by the immediate context and the participants involved. It is this unique aspect that allows SCR to transform everyday spaces into immersive, interactive arenas that blend the digital with the physical, engaging both active participants and the wider community in new and unexpected ways.

4.2 Intrinsic Characteristics of SCR

The essence of SCR lies in its intrinsic characteristics, which fundamentally shape the dynamics of interaction within public spaces. These characteristics highlight the unique aspects of SCR that differentiate it from other forms of digital and physical interaction, offering new opportunities and challenges for game design and public engagement. SCR naturally engenders a power imbalance between device wearers and non-wearers [4]. We propose a cross-user and cross-device dual-axis framework categorizing user experiences based on device immersion and user engagement.

4.2.1 Cross-Device Categorization

D0. No Device Incorporating "No Device" into our framework acknowledges the significance of traditional, un-augmented play and interaction within SCR environments. This category serves to highlight the importance of considering individuals in the vicinity of SCR activities who are not equipped with any digital augmentation devices yet remain integral to the social and interactive fabric of the space.

D1. Head-Mounted Display Devices Head-Mounted Display devices provide an immersive experience to players through the utilization of head-tracking and motion tracking to accurately track the position and orientation of the player's head in real time. This data is then used to generate a first-person view that corresponds to an egocentric view.

D2. Handheld Augmented Reality Devices Fixed Augmented Reality devices supports both first-person and third-person views. HAR devices allow players to observe the physical world un-augmented, while also providing the capability to observe the augmented scene on the screen. The device is held by the player, thus separating the device's movement from the player's head movement.

D3. Fixed Augmented Reality Devices Fixed Augmented Reality devices are anchored to specific physical environments, integrating them into the user's field of vision through stationary screens or installations. These devices offer a communal form of engagement, where multiple participants can share in the augmented experience simultaneously, albeit from a fixed perspective.

4.2.2 Cross-User Categorization

U1. Players Players are actively engaged participants who interact directly with the CR environment. Whether through HMD, HAR, FAR, or no device, players are characterized by their volitional involvement in the gameplay, exerting control, and making decisions that influence the game's outcome.

U2. Bystanders Bystanders are individuals who observe the CR gameplay without actively participating. This role is crucial in contexts where the CR experience is shared or public, as bystanders can significantly contribute to the social ambiance and collective experience. Design considerations for bystanders include providing meaningful ways to understand and potentially influence the gameplay or narrative from a non-participatory stance.

U3. Passersby Passersby are those who encounter the CR experience incidentally, without prior intent to participate or observe. This role highlights the permeability of CR experiences to the broader social and physical environment.

4.3 Intent Differentiation of HMD Wearers

Intent differentiation within SCR illustrates the varying objectives and levels of engagement desired by both HMD wearers and non-wearers. This diversity in intents shapes the dynamics of social presence and engagement in public spaces, presenting unique design challenges and opportunities for inclusive and engaging SCR experiences. Based on our in-the-wild studies, we summarize six levels of intents of HMD wearers (W1-W6). Specific examples are illustrated in Figure 1 (left).

W1. Unconcerned Players This group of people were indifferent to public perception while wearing HMDs, focusing solely on their immersive experience without regard to external views. As one player stated, *"I don't really care what people think when I'm playing. Once the headset is on, I'm in my own world. If people want to stare, let them."*.

W2. Privacy-Conscious Players Some HMD wearers preferred to keep their gameplay private, avoiding drawing attention. They sought discreet engagement, minimizing external observation and interaction. A more discreet player explained, *"I always try to find a quiet spot away from crowds. It's not that I'm ashamed, I just prefer to keep my gaming private."*

W3. Acceptable non-Sharers Some HMD wearers desired social acceptance in public spaces but chose not to share their HMD experiences, maintaining a boundary around their engagement. One interviewee captured this mindset, saying, *"I'm fine with people seeing me play, but I'm not here to give demos or explanations."*

W4. Eager Sharers Some HMD wearers were enthusiastic about their HMD experiences and keen to share with non-wearers, aiming to demystify HMD activities and foster interest. An enthusiastic player exclaimed, *"You've got to see this! Here, let me show you what I'm seeing - it's mind-blowing!"* Another echoed, *"I love explaining the game to curious onlookers. It's like introducing them to a whole new world."*

W5. Casual Inviters Some HMD wearers were open to spontaneously including non-wearers, aiming to broaden their play space to incorporate nearby participants. One participant described their approach: *"If I see someone looking interested I'll say, 'Hey, you can join in with your phone if you want.'"*

W6. Enthusiastic Recruiters This is the most inclusive group, actively inviting non-wearers with headsets into their HMD realm, seeking to expand their interactive experiences through shared technology. A highly inclusive player stated, *"The more, the merrier! We always bring extra headsets to share. It's so much fun to introduce new people to the game."*

4.4 Intent Differentiation of non-HMD Wearers

Similar to the HMD wearers, we summarize seven levels of intents of non-HMD wearers (N1-N7). Specific examples are illustrated in Figure 1 (right).

N1. Indifferent Passersby Some individuals did not notice or express interest in HMD activities, remaining indifferent to the experiences unfolding around them. One passerby remarked, *"People playing games? I honestly didn't even notice."*

N2. Tolerant Observers Some were aware of HMD activities but did not bother to engage, accepting HMD games in public spaces as a part of public activity diversity. A tolerant bystander noted, *"It's not my cup of tea, but they seem to be enjoying themselves. As long as they're not in the way, I don't mind."*

N3. Disturbed Onlookers A few people felt uncomfortable or offended by public HMD activities, viewing them as intrusive or awkward, highlighting SCR's potential to disrupt public norms. One concerned individual expressed, *"It's unnerving to see people flailing about and reacting to things that aren't there. It disrupts the peace of the park."* Another added, *"I find it rude and inconsiderate to the rest of us."*

N4. Curious Spectators Many non-HMD wearers were interested in CR activities, willing to learn more and possibly observe closely, serving as a potential bridge for CR community engagement. An intrigued onlooker said, *"I've never seen anything like this before. I'd love to know more about what they're experiencing in there."*

N5. Included Spectators Some individuals were eager to observe the activities through smartphones, showing interest in the visual aspects of the experience. One participant shared, *"They showed me how to see the game on my phone. It's pretty cool to get a glimpse into their augmented world."*

N6. Ready-to-Join with Handheld AR This group of individuals were interested in participating with smartphone access, eager yet feeling limited by their device capabilities. An smartphone user commented, *"I'm having fun seeing bits of the game on my phone, but I wish I could fully dive in. Maybe I'll invest in that headset!"*

N7. Ready-to-Join with Head-Mounted Display A few non-HMD wearers were interested and equipped with necessary headset technology, fully prepared and enthusiastic about joining the CR experience. An equipped and eager participant exclaimed, *"I have my headset with me. Can't wait to be part of the action!"*

4.5 Limitations and Future Work

While our study provides valuable insights into the dynamics of SCR in public spaces, it has limitations. The use of a specific game (MOFA) may have influenced the types of interactions observed. Future studies should explore a wider range of SCR applications to gain a more comprehensive understanding of intent diversity. Additionally, longitudinal studies are needed to understand how intents and social dynamics in SCR environments evolve over time as these technologies become more commonplace.

5 Conclusion

Our study underscores the complexity of managing diverse intents in Spontaneous Cross Reality (SCR) environments. The interplay between wearers, bystanders, and passersby creates a rich but challenging landscape for interaction design. Based on our in-the-wild studies, we present the synthesized results of cross-device and cross-user categorizations of the intrinsic characteristics of SCR. In addition, we report our observations of various intent differentiation of HMD wearers and non-HMD wearers. Future SCR systems will need to balance the immersive experiences of wearers with the inclusion and comfort of non-HMD wearers to achieve widespread acceptance and utility in public spaces. By addressing the challenges identified in this study and implementing the proposed design recommendations, we can work towards creating SCR experiences that are not only technologically advanced but also socially harmonious and ethically sound. As SCR technologies continue to evolve, ongoing research and thoughtful design will be crucial in shaping a future where digital and physical realities seamlessly coexist in our shared public spaces.

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