SocialCueSwitch: Towards Customizable Accessibility by Representing Social Cues in Multiple Senses

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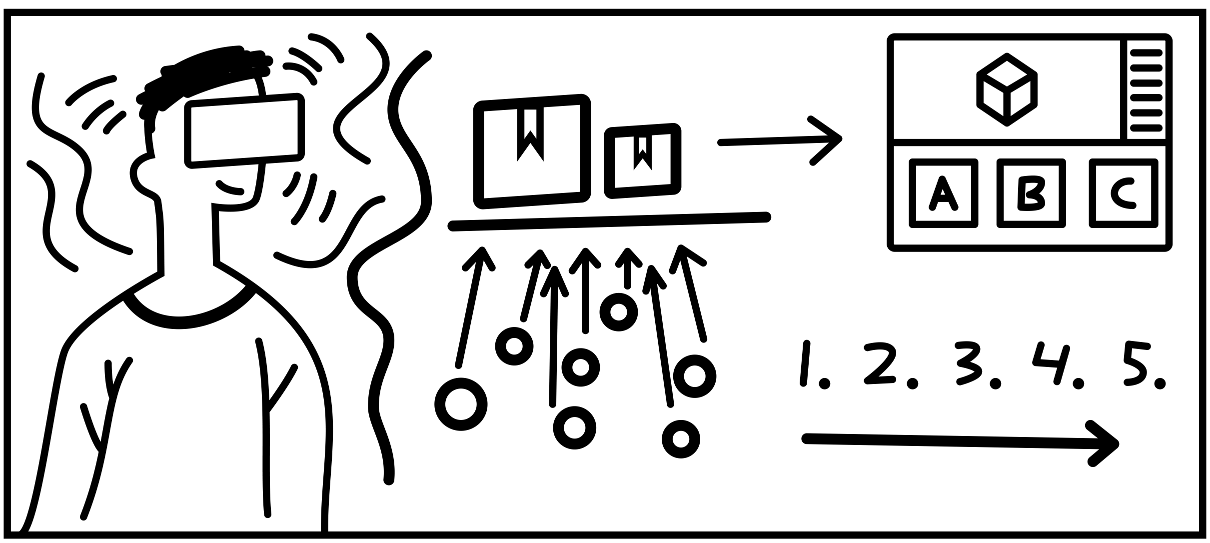

Figure 1: Illustration showing VR users benefiting from the development and distribution of accessibility tools. Three components from left to right: A VR user with a headset with lines illustrating sensory cues, circles indicating many labs building packages pointing at one package distribution tool; A program such as Unity to build VR projects as well as a counter illustrating tool iteration.

ABSTRACT

In virtual environments, many social cues (e.g. gestures, eye contact, and proximity) are currently conveyed visually or auditorily. Indicating social cues in other modalities, such as haptic cues to

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complement visual or audio signals, will help to increase VR's accessibility and take advantage of the platform's inherent flexibility. However, accessibility implementations in social VR are often siloed by single sensory modalities. To broaden the accessibility of social virtual reality beyond replacing one sensory modality with another, we identified a subset of social cues and built tools to enhance them allowing users to switch between modalities to choose how these cues are represented. Because consumer VR uses primarily visual and auditory stimuli, we started with social cues that were not accessible for blind and low vision (BLV) and d/Deaf and hard of hearing (DHH) people, and expanded how they could be represented to accommodate a number of needs. We describe how these tools were designed around the principle of social cue switching, and a standard distribution method to amplify reach.

CCS CONCEPTS

• Human-centered computing → Accessibility systems and tools; **Accessibility theory, concepts and paradigms**; **Accessibility technologies**; **• Software and its engineering →** *Open source model*.

KEYWORDS

code sharing, accessibility, sensory substitution, collaborative development

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1 INTRODUCTION

Social virtual reality (VR) has the potential to provide a richer experience for social interactions than other methods of online communication such as video conferencing [2]. Even more importantly, the unique affordances of VR can potentially make meetings using social VR broadly accessible by providing additional support such as highlighting important context, captioning, and audio overlays [26]. However, while the promise of social VR is great, these systems are currently not accessible to all, especially blind and low vision (BLV) and d/Deaf and hard of hearing (DHH) people, because many of the social cues that make social virtual reality experiences more rich and engaging are only represented visually or audibly.

However, just as these social cues are of broad interest, so their representation should be configurable to maximize their usefulness for diverse audiences. For example, a DHH person may prefer certain visual cues but find others too stimulating. A BLV person might wish to use specific sounds to represent specific social behaviors, or use haptic cues instead of audio cues when speaking or listening. Other users may additionally find these tools helpful, for example, neurodivergent users who may wish to selectively block out some cues, or amplify others. Allowing users to customize the sensory rendering or combination of renderings (audio, haptic, or visual) can accommodate individual preferences and contexts. In this way, we follow the example of existing tools such as Scene Weaver, which argue that the customization of accessibility tools is essential for them to be adopted [7]. For users of different abilities, such as BLV or DHH people, their different sensory capabilities doesn't have to be a hindrance to experiencing social VR. For example, a d/Deaf and hard of hearing person should have the option for text based cues if auditory input is challenging. This allows users to not only accommodate their individual differences, but also to adjust how social cues are represented depending on the context of the interaction [31]. Thus, individuals can use different sensory modalities to understand behaviors of common interest; for example: Who is paying attention to me? Who is approaching me? Who is speaking, and to whom? Virtual reality is uniquely able to identify social cues, and allow them to be represented in multiple modalities, which can be customized to users' preferences [6]. Our contributions are as follows:

- We present an argument for "social cue switching" to enhance accessibility research.
- We present a "sample" SocialCueSwitch toolkit based on allowing users to customize how social cues are rendered.

Below, we briefly review current work on accessibility in social virtual reality, as well as the history of transforming social interaction to create novel representations of social behavior. We then propose an approach to address the challenges of making social VR cues broadly accessible. We describe some sample tools to address these issues for BLV and DHH users, and how we systematically developed and shared these systems.

2 RELATED WORK

We draw on three areas of related work. First, we discuss accessibility issues in social VR, focusing on BLV and DHH users as groups who are explicitly excluded from many social cues. Next, we discuss how the concept of "transforming social interaction" was originally proposed as a way that immersive VR could improve on physical-world, face-to-face interactions, and how tracked behavior can be rendered in a number of different ways. Finally, we discuss the current state of sharing accessibility solutions.

2.1 Current Accessibility Solutions

The full potential of social VR has yet to be realized [8]. Despite social VR's capacity to reinvent social interaction, it is not currently very accessible to BLV and DDH users [36, 45, 51]. Improving accessibility is a crucial step to make social VR experiences broadly useful [29]. Moreover, a system that uses the special affordances of immersive VR can enrich social interaction for all users. Providing multiple sensory representations of key social behaviors could add depth to social cues and expressions, creating more engaging experiences in social VR. Two paths exist for making VR more accessible; developing custom hardware that has additional functionality not present in the headset or building software to augment pre-existing systems. In this paper we will focus on software solutions.

2.1.1 Visual Accessibility. Since its inception, VR has been a visually-dominant medium, creating a significant barrier for BLV people when using VR devices [30]. There has been a considerable amount of work exploring how to make VR accessible for BLV people through hardware [17, 24, 43, 49], software [3, 10, 29], and mixed reality using a combination of both custom hardware and software [22, 46]. Existing tools such as VRBubble have addressed how to represent some social cues such as proximity [21].

In social VR, interactions often rely on a combination of visual cues such as gestures, avatars, and text chats, and many tool sets focus on a primary sensory impairment such as displaying visual stimuli auditorily [1, 3, 11, 21]. This is also true for auditory accessibility, as we discuss below.

2.1.2 Auditory Accessibility. Specialized audio in VR can enhance immersion to an extent comparable to significantly improved video quality [37]. The richness of audio communication extends beyond verbal interaction, encompassing prosodic communication, and environmental sounds, all of which contribute to the immersiveness of the experience. However, closed captioning and subtitling features are complex to integrate into spatial interactive virtual reality, which diminishes the VR experience for DHH people. This is even more true in the context of social VR [18], especially multi-user VR environments, which can make the direction of sounds challenging to determine.

Visual representation of sound cues, including direction, intensity, and type, can enhance the comprehension of the VR space, making it more inclusive for DHH people. Recent research seeks to overcome these hurdles by visualizing sound within VR, for example, SoundVizVR proposed by Li et al. (2022) [20, 27, 28, 34]. These tool sets are not exhaustive, and existing studies encourage more exploration into novel tools.

2.2 The Transformative Potential of Social Virtual Reality

Social VR represents an exciting evolution of interaction, in which the boundaries of physical geography no longer limit social connectivity [13]. Social VR platforms such as VRChat and Horizon Worlds are becoming increasingly sophisticated, incorporating real-time voice chat, hand gestures, and even facial expressions to enrich social dynamics within a virtual environment [33]. These platforms allow users to have a sense of presence and co-location with others that traditional social media or video conferencing cannot match because of the lack of embodiment [35].

Beyond the ability to recreate face-to-face interactions more realistically, social virtual reality allows the ability to interact in ways that are impossible in the physical world. While some work such as Hamad et al. argues for virtual reality as better able to replicate interactions happening in the physical world than 2D media (examples include driving simulators, educational experiences, and medical training) [16], VR can also support methods of sensing tracked behavior that aren't possible in other mediums, such as synchronous behavior between two individuals [44]. As was pointed out in a germinal paper, [6], any experience in VR is based on tracked behavior that is then rendered to the user through sensory interfaces. However, the way tracked behaviors are rendered can be very different, providing more information than in the physical world, or presenting that information in a more accessible or more engaging way.

Early proposals for transforming social interaction included examples of making invisible but socially relevant behaviors more explicit, for example, by visualizing the direction of gaze of the speaker, so they could be more conscious of their own behaviors [15, 40]. However, the behaviors of others can also be transformed, for example, through lines illustrating where people are looking to see how these affect social interaction [32]. Because the behavior of all avatars in a space is tracked, social cues that depend on the behavior of more than one user, such as nonverbal synchrony, can also be rendered in a way that makes them more explicit [41]. Other 'transformative' augmentations can include adding other social entities, such as a "monster" that looks at who is speaking most [32].

To create accessible VR, a significant challenge is to ensure that people with different sensory abilities gain a full experience [30]. Here, the concept of sensory substitution [5] comes into play. Sensory substitution refers to the use of one sensory modality to provide environmental information normally collected by another sensory modality. This can improve the accessibility of virtual environments [29]. In the context of VR, it can mean using sound or haptic feedback to convey visual stimuli to BLV people or vice versa. Our approach is more calibrated. Rather than suggesting sensory substitution alone as a solution for accessibility, we focus on making social cues available to users through multiple sensory channels which can be customized to create an individual experience. In other words, we aim to capture and represent social behaviors that are of broad interest, but promote a framework in which they can be represented in a customizable way. This principle of "social cue switching" can guide the development of tools that allow customization and adaptation based on individual user needs.

3 TOOLKIT DESIGN

Accessible social cues are vital in complex social environments [35]. ased on previous work [14, 21, 38, 42], we selected four social cues (active speaker detection, gaze direction detection, gesture detection, and proximity detection) that were relevant to both BLV and DHH users, and developed multiple methods of rendering these social signals. Below, we describe each cue, as well as example modalities in which they can be rendered.

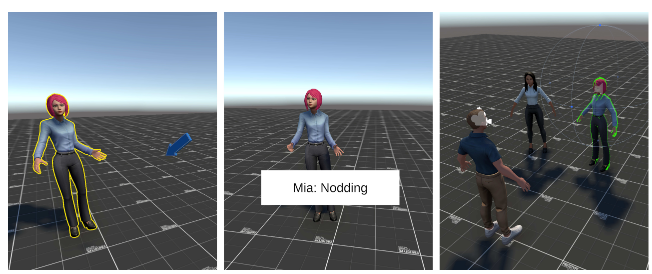

Figure 2: Images from left to right: Audio Cue from proximity, Audio Cue from Eye Contact, Audio Cue from Head nodding

Detection of the Active Speaker. Understanding who is currently speaking is important during an interaction. There are many reasons why it may be difficult for someone to detect who is speaking [19, 39]. Examples include BLV people who can't detect the speaker visually, or DHH people who may have a hard time identifying who is talking to them when multiple people are speaking at the same time. However, others may also find such a tool useful. People with mobility issues who may struggle to orient themselves in the direction of the active speaker in a timely manner, or people with sensory processing issues who may have preferences for specific modalities could additionally find this tool useful. There are multiple ways to indicate who is speaking in a virtual environment. Our toolset has an option to highlight the speaker as they speak as a visual indicator of who is talking. Another option is a caption that indicates who is speaking, which can also be rendered as an audio cue. In addition to these methods, if the user does not have the speaker in view, an arrow can be rendered to point in the direction of the active speaker. For BLV people, this tool uses spatial audio to indicate the active speaker's direction, while for DHH people, visual cues and captions provide clear identification, ensuring all users can follow conversations.

Gaze Direction Detection. Eye contact is an important social cue, indicating focus, attentiveness, and interest, among other things. This makes indicators of eye contact or gaze generally valuable [9, 48]. To determine whether eye contact is established, the tool utilizes a raycast to see if two participants are looking at each other. This information can then be rendered as an audio cue, caption, or using haptics indicating who is making eye contact with the user, and when. To capture peripheral vision we use an invisible cone mesh, providing a broader spatial understanding which can also be rendered as a caption, audio cue, or haptic cue. In the current version of this project, when a user is speaking, a caption will inform them of who is gazing at the speaker. Direct and peripheral gaze can also be represented by two distinct audio cues: a low-volume sound indicating peripheral vision engagement and a louder, more distinct sound for direct gaze. When using haptic cues, the controllers will vibrate when a person is gazing at the user. The audio cues are designed to be subtle peripheral sounds, ensuring they do not interfere with conversations. This tool allows BLV users to discern when they are the focus of someone's gaze, whereas DHH users benefit from visual notifications, making nonverbal cues accessible. It's worth noting that for this tool, we use head position as a proxy for eye gaze to make this feature work for commonly available, inexpensive headsets like the Meta Quest 2, which lacks eye-tracking functionality. Future iterations can incorporate eye-tracking technologies available in more advanced headsets.

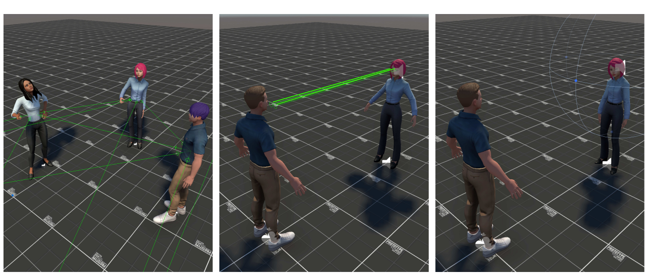

Figure 3: Images from left to right: Visual Cue for sound direction, Caption from Head Cue Contact, Highlighting of speaker

Non-Verbal Gesture Detection: Understanding social cues such as head nodding can be a hurdle for BLV people, especially in VR [42], and these can also be missed by DHH people who are simultaneously monitoring closed captions or other information visually. People who have a hard time identifying subtle social cues, such as individuals in the neurodivergent community, may also find this tool useful. Currently detected gestures include head nodding and shaking your head. These are detected programmatically based on the coordinates of the tracked head element. Developers can add any other gesture by making a detection algorithm and plugging it into the existing toolset. Identifying these cues in a more salient way will give people more options on how they prefer to see these nonverbal gestures. This tool captures these gestures and renders them as captions identifying the person who made the cue and what cue they made i.e., "Person One: nodded their head" or playing an audio cue that indicates "Person One" is nodding. The audio feedback for gestures is balanced to complement speech, allowing the audio to be a peripheral sound. This tool enables BLV people to 'hear' nods or shakes, and DHH people to 'see' these gestures through on-screen indicators, allowing all people to understand non-verbal gestures. Such cues could replace, or reinforce, visual information.

Proximity Detection: Those who struggle to perceive proximity, or the relative distance between themselves and others, are missing important nonverbal information [21]. This tool calculates the distance vector between the user's avatar and other avatars in the VR environment. This information can then be rendered auditorily and/or haptically. When audio is used, it is a base 220 hz wavelength that gets upshifted and downshifted. When rendered haptically, the value changes from zero to one based on the same vector, providing the user with a sense of relative distance. This technique differs from Ji et al. which used defined conversational zones [21]. The calculation is dynamic, and the distance threshold at which the cue begins is configurable, allowing a level of customization to cater to individual needs. In more complex social situations with multiple people the tool gradually increases the volume to indicate there are more people present. These transformations not only cater to BLV and DHH people but also to users who prefer visual or audio cues, find themselves in noisy environments, or simply wish to have extra tools to be able to monitor their environment closely.

3.1 Standardizing and Enhancing the Reach of Accessibility Toolsets

There have been numerous accessible VR tools developed by the academic community. These tools have made tremendous strides in making VR more accessible, but are sometimes shared in a fragmented and unstandardized way [14, 38], limiting their reach and use by the broader community. Projects hosted on personal GitHub Pages receive minimal exposure, generally only to those who have read the related paper or are familiar with the authors' work. The option of hosting these tools on large company websites is not available for many researchers [50].

Package management tools show one potential pathway for increasing exposure of VR tools. Many tools are built as Unity Packages [27] and could easily be published to the Unity Asset store, but few have gone through the steps to publish them (a search for "accessibility" on the Unity Asset store yields 16 results, a similar search on the ACM digital library for "vr accessibility tools" returns 394,579 results). Many VR tools, designed for single-use projects, often lack robust documentation and reuse-oriented design which impedes other developers' ability to adapt and innovate with these tools in a rapidly evolving VR field [4]. We addresses this gap by providing documented, easily extendable code that can be a starting point for new projects or easily integrated and extended for quickly adding accessibility tools. A universally designed social VR system could make virtual social interactions more accessible, immersive, and engaging, marking a leap forward in the accessibility of social VR.

We follow [12, 27, 47] in emphasizing the importance of well-documented, reusable code packages in cultivating an inclusive VR development ecosystem. This documentation allows easy understanding and extension of our toolkit.

4 DISCUSSION

In this short paper, we introduced a set of tools developed in Unity that enhance accessibility in VR for users with visual and auditory impairments, but can be flexibly extended to accommodate individual users' needs and preferences. These tools capture proximity, eye contact, active speaker status and head nodding in social virtual reality, and render these social cues using other sensory modalities, creating a more inclusive and customizable VR experience.

4.1 Limitations

This paper introduces some tools that may add to efforts to enhance social VR accessibility, but next steps must include feedback from users to address limitations and unmet needs.

While improving VR accessibility, we acknowledge the ethical responsibility to ensure these tools respect user privacy, specifically in how data is used and stored.

Additionally, tools such as these may impact social dynamics, and future work should examine the experience of having one's behaviors tracked and rendered in different modalities.

Our initial approach focused on single cue interactions. Curenbtly, users may handle complex scenarios with overlapping audio and visual cues by selecting preferred modalities for a given situation. However, designing a more graceful approach to handling overlapping cues is a future direction for this toolkit.

4.2 Future Work

We have discussed our efforts to make this toolkit shareable. Implementing the toolset on top of the Oculus Unity SDK ensures broad compatibility and ease of integration, making accessibility enhancements more widely available to developers. The true value of a shared toolset is realized when it is adopted, modified, and improved by a wide range of developers and researchers, and publishing tools made to a centralized repository of systems will allow more people to find and use these systems. However, by using Unity, the Oculus SDK, and other third-party libraries, we run the risk of these systems becoming outdated, unsupported, or having features we rely on removed. Future work could expand compatibility with other VR platforms and SDKs.

Looking beyond the current applications, there are numerous other potential uses for social cue switching. As discussed above, one such area is integrating our toolkit into VR experiences for neurodiverse users. VR has significant potential to support the neurodiverse population by creating customized immersive environments that accommodate individual sensory needs and preferences [23]. For instance, people with ADHD, who may struggle with traditional visual cues and multitasking in complex social scenarios, might find the clear, single-channel auditory cues beneficial. Our toolkit could aid in these endeavors by providing a flexible and adaptable toolkit for sensory substitution, allowing developers to customize VR environments based on individual sensory profiles.

Finally, the social cues we have used in our sample kit are only a small subset of the rich set of social information available in social virtual reality, and the sensory modalities we have used to render these cues represent only a tiny fraction of the potential interactions. As previous work has demonstrated, he creativity of the accessibility community and of social virtual reality users in general can expand the transformation of social cues in ways that enrich social experiences for all.

5 CONCLUSION

VR systems are still changing rapidly, and many important accessibility features are not yet robust and standardized. While we aim for our current toolkit to be another step towards more inclusive VR experiences, multiple areas remain for future exploration and improvement.

Our toolkit focuses on modalities that translate cues from one sensory modality to another. For BLV people, visual cues are represented auditorily, and for DHH people, audio cues are represented visually. While these tools for social cue switching are a start in approaching a customized user-specific social VR accessibility system, the toolkit can be further expanded and refined. Our current toolkit is designed to work seamlessly with the Oculus Unity SDK, but future work could expand compatibility with other VR platforms and SDKs. We follow the example of systems like REC, a tool developed by Gorisse [14]. By allowing and encouraging others to use these tools in their projects, more robust platforms can be created. Research has shown that open source tools receive support as developers are motivated by an array of reasons such as career advancement, personal enjoyment, and altruism [25]. As the toolset's effectiveness is contingent on widespread adoption and iterative improvement, devising methods to foster an active, collaborative community around the toolset will be a key area for future work.

6 DATA AVAILABILITY

The source code and related files used in this project are publicly accessible and can be found at the following GitHub repository: https://github.com/virtual-embodiment-lab/SocialCueSwitch The package can additionally be found on the Unity Asset Store: https://assetstore.unity.com/packages/tools/utilities/socialcueswitch-259078

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