Report from Dagstuhl Seminar 24371

Extended Reality Accessibility

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Abstract

Extended Reality (XR), including Augmented Reality (AR) and Virtual Reality (VR), technologies are on the cusp of becoming mainstream. In 2019, about 6 million VR and AR headsets were shipped worldwide, with an estimated 16.5 million headsets in use in 2021, and predictions of over 50 million by 2026. By some estimates, this represents a $1 trillion market. Ideally, these technologies would be accessible to all who desire to use them; however, today, XR technologies are not accessible to millions of people with disabilities or impairments (visual, motor, cognitive), with incompatible physical characteristics (e.g., hairstyles and head shapes), with health conditions, and beyond. This includes children and the growing group of elderly people. In particular, the low accessibility of these technologies today hinders their widespread adoption worldwide, especially in the educational systems (learning, training), in industry (training, assistance), and in health care (rehabilitation, therapy, telemedicine). Thus, this Dagstuhl Seminar addressed an urgent need in the field to ensure that all individuals can benefit from the applications that XR offers.

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1 Executive Summary

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In the past, when new technologies emerged, making them accessible was always an afterthought. However, retroactive accessibility is never as effective as accessibility that is built-in from the start. Simply put, we must act to make extended reality (XR) accessible now.

The expertise of the organizers and seminar invitees allowed us to focus on specific areas of accessibility including visual, auditory, and motor disabilities or impairments as well as cognitive impairments that may occur with very young or older users. Research questions that we focused on include (but were not limited to) the following:

- How can we make XR more accessible for those who are blind or have uncorrectable low vision?
- How can we display captions or augment XR experiences for deaf individuals?
- How can we make controllers for XR compatible with various motor impairments?
- How can we adjust XR displays to accommodate smaller head sizes of young users?

This Dagstuhl Seminar builds off of the ground-breaking work that has been done in this area, in particular the XR Access Initiative, which was founded to bring together people across industry, academia, advocacy organizations, and government. While these initiatives have been mostly confined to participants from the United States and Canada, this seminar allowed us to expand the reach of these initiatives to a more international audience that will bring new perspectives and solutions. Making XR accessible to everyone will depend on the involvement of researchers from around the world. In the Outcomes section below, we introduce ideas generated at the seminar to make interdisciplinary fields more aware of the field of XR accessibility in order to create more research on the topic but also to increase awareness.

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3 Overview of Talks

Seven presentations were given during the seminar. In general, the format of the seminar was to engage participants in working groups around areas of interest in the group under the main theme of the seminar – accessibility. Specific talks were invited to be given by experts or stakeholders (who were already present as attendees) in particular areas of interest. These talks were meant to further ideas about future goals for XR accessibility as well as to spark discussion among group members or ideas for new research avenues. The talks were set to be a shorter format (i.e., 30 minutes at most) in order to facilitate question and answer sessions as well as greater discussions amongst groups or attendees.

3.1 Accessibility and Inclusive Information Technologies

Steffen Puhl (Universität Gießen, DE)

Dr. Steffen Puhl, Coordinator for Accessibility and Inclusive Information Technologies at the IT-Service Center (HBZ), presented on the efforts to enhance accessibility in virtual and augmented reality (VR/AR) environments. Since 2020, accessibility has been a key focus for the VR/AR working group at Universität Gießen. In 2021, the Lab for Innovative Teaching launched the NIDIT project[1], and by 2022, initial results on improving VR access were shared with colleagues from ACCESS@KIT[2].

The primary focus of these efforts has been the inclusion and participation of blind and visually impaired (BLV) students and teachers in VR learning scenarios. The approach involves identifying the needs of this group, developing relevant content, and programming and evaluating a demo application. The overarching goals are to make VR usable for the target group and to make existing systems accessible, thereby creating immersive experiences that are tangible for BLV users.

The team examined various available platforms, including Spatial, Engage, 3 Spin Learning, Mozilla Hubs, Unity, Unreal Engine, and Blender. However, they found that existing platforms like Spatial and Hubs were not flexible enough, necessitating the creation of new solutions. Basic requirements for the learning scenarios were identified, such as audio, navigation, walking, leaning interfaces, teleportation, and traveling.

Understanding the structure of a room and who is present when entering a VR space is crucial. In real life, BLV individuals can explore their surroundings using a cane, hands, or by asking a sighted guide. Equivalent methods need to be developed for VR. The next steps include securing funding for technical equipment and experts in spatial audio engineering, 3D modeling, programming, learning architecture, and audio description. Additionally, the research will expand to include other fields, such as transitions for people with higher residual vision and other disabilities.

[1] https://www.uni-giessen.de/en/study/teaching/projects/nidit/network-for-impactful-digital-teaching-skills-nidit?set_language=en
[2] https://www.access.kit.edu/index.php

3.2 Making Virtual Reality More Accessible for Persons with Balance Impairments (e.g., me)

John Quarles (University of Texas – San Antonio, US)

In a presentation titled "Making Virtual Reality More Accessible for Persons with Balance Impairments," Dr. John Quarles discussed the challenges and potential solutions for individuals with balance impairments, particularly those caused by conditions such as multiple sclerosis (MS). Quarles, who uses a wheelchair due to his inability to walk long distances, highlighted the significant balance issues he faces, especially in virtual reality (VR) environments. Following a severe MS attack, he found VR usage nearly impossible without falling over, a problem that extends to all users to some degree due to the inherent imbalance issues VR can cause.

To address these challenges, Quarles explored the effects of various auditory feedback techniques on improving standing balance in VR. He conducted a user study with 42 participants, half of whom had balance impairments primarily due to MS or diabetes. The study involved a standing reach and grasp task under different conditions: a baseline with no VR, and several VR conditions with different types of auditory feedback. These included spatial audio (spatialized white noise), static rest frame audio (white noise in HMD headphones), rhythmic audio (white noise beats at one-second intervals), and center of pressure (CoP) audio (pitch and stereo adjustments based on balance board data).

The results indicated that VR without feedback worsened balance compared to the baseline. However, the CoP and spatial audio techniques significantly improved balance, providing more information about balance than what is typically available in the real world. This improvement was observed in both participants with and without balance impairments, demonstrating a "curb cut effect" where accessibility features benefit all users. Follow-up studies replicated these findings with tactile and visual feedback, as well as walking tasks, showing similar results. Multimodal feedback (e.g., tactile and audio) yielded stronger results but also introduced potential information overload.

Quarles concluded that spatial and CoP auditory feedback were the most effective, followed by rhythmic and static rest frame audio, with no audio being the least effective. This research assists developers in creating more accessible and usable VR experiences for individuals with balance impairments. Future work will focus on busy, stimuli-rich virtual environments and adaptive feedback tailored to individual needs and virtual contexts.

The presentation also touched on the potential for longitudinal studies, where systems could be installed in users' homes to provide continuous support. Questions were raised about the feasibility of using platforms like Kinect or software-based solutions to eliminate the need for balance boards. Additionally, the discussion included the importance of supporting disabled researchers and speakers through fellowships, scholarships, and volunteer opportunities, as well as the need for more alignment and mentorship across conferences to foster long-term engagement and support for accessibility in VR.

3.3 XR Access

Dylan Fox (Cornell Tech – New York, US)

Dylan Fox presented on XR Access, a research initiative of Cornell Tech. Led by Executive Director Shiri Azenkot and Director of Operations Dylan Fox. Its goal is to make Extended Reality (XR) accessible to people with disabilities. After reviewing the ongoing research and advocacy work of XR Access, Fox led a discussion on how it could help the gathered researchers conduct and share their research.

Research. Dr. Azenkot's lab and allies at Cornell Tech lead research in multiple topics, including AI scene descriptions and VR sighted guides for low-vision or blind people, as well as avatar representation for those with invisible disabilities. In particular, Fox discussed recent research on AI Sighted Guides, which compared multiple iterations of AI guides designed to enable blind individuals to navigate and learn about VR environments.

Connections and Resources. XR Access connects researchers together with other key stakeholders by multiple methods. Their Research Network connects researchers and gathers the latest topics, while shining a spotlight on great science via their seminars and community discussions. They also host an annual Symposium in New York, and provide a compendium of resources and open challenges via their website.

Standards. Recognizing the importance of advancing standards for accessible XR, XR Access contributes to standards bodies such as the FCC, W3C, and IEEE. Additionally, they have cofounded the Metaverse Standards Forum Accessibility Working Group, which will publish comprehensive guidelines on accessibility by 2027.

Advocacy and Community. XR Access sends representatives to many conferences both academic and industrial, such as IEEE VR, AWE, and DEFCON. They also advise organizations such as Meta, and host their own community of thousands of researchers, content creators, disabled people, advocates, and more. Their community has done volunteer projects such as XR Access Stories, which documented the stories of 5 disabled users of XR to capture the real-life impact of inaccessibility.

Overall, the talk served to highlight the capacities in which XR Access serves to advance the accessibility of emerging XR technologies, and offer its services and resources to the gathered researchers.

3.4 Envisioning Access

Diane Nahabedian (Envisioning Access – Boston, US)

Diane Nahabedian's presentation on "Envisioning Access" highlighted her personal motivation driven by witnessing disability impacts within her household. She discussed the evolution of her 45-year-old organization, originally Helping Hands: Monkey Helpers, which transitioned from training monkeys for spinal cord injury support to exploring technological solutions due to legislative changes. The organization now focuses on testing and incubating technologies to aid disabled adults in returning to work or school, collaborating with companies like Cognimate on innovations such as a glove for stroke survivors, robotic canes, exoskeletons, and exploring AR, VR, and AI. She called for developers to collaborate, emphasizing their base in Boston, Massachusetts, and their nationwide client reach.

3.5 Sensory Input Matrix

Tobias Langlotz (University of Otago, NZ)

Dr. Tobias Langlotz's presentation on the "Sensory Input Matrix" focused on addressing the needs of individuals with low or no vision by exploring the design space for vision augmentation. The matrix he discussed outlines possible remappings of sensory inputs, such as converting auditory signals to haptic feedback, which can be applied to both accessibility and assistive technologies. This approach is independent of specific applications and aims to compensate for missing sensory cues. Langlotz emphasized the importance of considering both input and output modalities, suggesting that VR could be used to simulate disabilities and evaluate accessibility. He also highlighted the need for collaboration among researchers to refine the taxonomy and explore multimodal aspects, while noting the potential benefits of publishing separate papers to cover different areas comprehensively.

3.6 Towards Accessible XR: Technical Opportunities for Developing and Appropriating Applications

Anthony Steed (University College London, GB)

Dr. Anthony Steed's presentation on "Towards Accessible XR: Technical Opportunities for Developing and Appropriating Applications" highlighted the potential for enhancing accessibility in XR by integrating code at the XR runtime and signal composition levels. He discussed how tools like WalkinVR[3] and Ubiq[4] operate at the sensor hardware and driver levels, making applications unaware of their presence. Steed emphasized that functionalities like teleportation should be managed by the runtime rather than individual applications. He pointed out the need for collaboration with OpenXR to make scene compositors available, which would allow for more extensive modifications and accessibility features. Steed also addressed the challenges and opportunities with different platforms like SteamVR and Quest, noting the limitations and security concerns of each. He suggested that a more open composition layer could facilitate better accessibility without requiring game developers' permission. Additionally, he mentioned tools like VR Hook and RenderDoc for low-level system access and data collection, including real-time cybersickness metrics.

[3] `https://www.walkinvrdriver.com/`
[4] `https://ubiq.online/`

3.7 The Virtual Experience Research Accelerator (VERA)

Gregory Welch (University of Central Florida – Orlando, US)

Dr. Gregory F. Welch, Professor at the University of Central Florida, presented on the Virtual Experience Research Accelerator (VERA)[5] project that is a human-machine system for carrying out human subjects research related to extended reality (XR), including virtual reality and augmented reality, for the XR researcher community. The project also seeks to foster a vibrant, diverse, and inclusive VERA research community, and to foster the professional growth of individual researchers. The mission of the VERA project is to serve the community of XR researchers by providing tools to accelerate and improve the quality of their human subjects research, building and sustaining a diverse and inclusive collaborative community of XR researchers, and fostering the next generation of XR researchers. The discussion focused on accessibility in the scope of the VERA project. The discussion will be continued at the upcoming ISMAR 2024 conference in the form of a tutorial organized by Dr. Welch.

4 Working Groups

During the seminar, we formed seven working groups that were focused on different topics related to XR accessibility. We first set up a shared, online board where attendees could create notes on topics of discussion that they would like to see discussed in our seminar over the week. People nominated topics on the first morning of the seminar or before they arrived. Each attendee could nominate as many topics as they liked. On the first day of the seminar, all of these topics were presented and attendees had the opportunity to do an online vote for the ones they were most interested in discussing in the working groups. The topics that received the highest number of votes were prioritized for the working group discussion sessions. Attendees chose which working group to attend based on personal interest and the groups met for a half of a day. Once group discussion had finished, all groups reconvened with the rest of the seminar attendees and presented their discussions in terms of outcomes and recommendations for further research opportunities. Some main outcomes came from these groups. First, all of the groups pledged to continue pursuing their interests in the topics after the seminar. Many have met since the seminar ended. General ideas that crossed groups were pursued by all attendees of the seminar. As is stated in the outcomes section below, one important future outcome was the organization of a group that proposed a workshop on the topic of this seminar for the IEEE VR 2025 conference. A future position paper that includes the entirety of the group (or whomever would like to be included) and highlights the outcomes from each of the working group discussions is also planned.

[5] `https://sreal.ucf.edu/vera/`

4.1 Working Group on Social Interaction in XR

Tiare Feuchtner (Universität Konstanz, DE)
Yuta Itoh (The University of Tokyo, JP)
Kiyoshi Kiyokawa (Nara Institute of Science and Technology, JP)
Ernst Kruijff (Hochschule Bonn-Rhein-Sieg, DE)
Torsten Kuhlen (RWTH Aachen, DE)
Robert Lindeman (University of Canterbury – Christchurch, NZ)
Anne-Hélène Olivier (Inria & University of Rennes 2, FR)
Tabitha Peck (Davidson College, US)
Alexander Plopski (TU Graz, AT)
Adalberto Simeone (KU Leuven, BE)
Laura Trutoiu (Facebook – Redmond, US)
Gottfried Zimmermann (Hochschule der Medien – Stuttgart, DE)

In the working group session on "Social Interaction in XR," the discussion was divided into two main themes: "The Box" and "Avatar Representation and Control."

The Box. This concept revolves around a central communication hub, referred to as "The Box," which facilitates social interactions among participants. In this setup, three individuals (P1, P2, and P3) communicate through The Box, which translates and maps their communications into media appropriate for each participant. This model has various applications, including education, health and rehabilitation, gaming, employment, tourism, entertainment, and emergency services. Key requirements for this system include hybrid participation (remote participants as avatars), configurable fidelity of avatar representation (termed "functional realism"), and comprehensive communication modes (video, audio, real-time text). Accessibility services such as AI-driven captioning, audio description, sign language translation, and easy language translation are essential. Additionally, a feedback loop mechanism is necessary to ensure clarity and understanding during interactions.

Avatar Representation and Control. The second group focused on the flexibility and customization of avatars. User Representations (e.g., virtual avatars in VR) are fundamental for self-perception, interaction with the environment, and social interactions in multi-user environments. In this context, the group have discussed both *static* and *dynamic* properties of the user representation: for example, static properties may include differences in body morphology (e.g., absence of limbs) or commonly used mobility aids, and dynamic properties could reflect abnormal gait or tremors. Recent studies exploring how users with disabilities would like to be represented in XR have shown that they may want to reveal or hide their visible or invisible differences in ability depending on the interaction context. While current libraries support customization and personalization of virtual avatars to reflect cultural and gender diversity (e.g., VALID Library[6]), adaptations are then commonly limited to modifications of the texture and minor mesh deformations. In the context of accessibility, Meta and Bigscreen alone provide respectively hearing device accessories for individuals with hearing deficits, and eye patch accessories for individuals with visual deficits. However,

[6] https://github.com/xrtlab/Validated-Avatar-Library-for-Inclusion-and-Diversity--VALID/

adaptations of the animated avatar rig (skeleton) that would be needed to reflect a specific body morphology and its related dynamics, are commonly not supported. Control over avatars extends to their motion. We discussed the consideration for motion filters to animate avatars according to individual motion patterns. Adaptive locomotion metaphors should be explored to maintain realistic and socially acceptable trajectories in virtual environments. We also questioned the evaluation of these systems with the need of assessing the relevance and appropriateness of current questionnaires for specific situations, balancing accessibility with social acceptance.

Challenges and Future Directions. We must support further customization options that facilitate representing visible and hidden individual capabilities considering both the static and dynamic properties of the user's representation. AI integration could enable prompt-based avatar generation (e.g., "Wheelchair, Tom Hanks, Beach, Japanese") that could be further modified by the user, if needed, to avoid tedious manual adaptation of a myriad of characteristics. Further, to allow the users to show and hide their difference in capabilities to the Box (for example), their representation should offer the flexibility to change over time. Such challenges would required further development in tracking approaches, animation pipelines and interaction techniques. Several outcomes are considered: 1) the proposal of student projects, 2) the preparation of a survey of existing avatar creation tools, including the identification of the important avatar attributes for disabilities, and the comparison of these attributes with those currently available in existing systems to identify gaps. Especially, the question of the dynamic properties of the virtual human is crucial, 3) the inclusion in the call for IEEE VR Workshop Virtual Humans and Crowds in Immersive Environment the question of accessibility.

4.2 Working Group on Accessible Tangible Games

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Lauren Buck (University of Utah – Salt Lake City, US)
Dylan Fox (Cornell Tech – New York, US)
Makoto Kobayashi (Tsukuba University of Technology, JP)
Ernst Kruijff (Hochschule Bonn-Rhein-Sieg, DE)
Eike Langbehn (HAW – Hamburg, DE)
Diane Nahabedian (Envisioning Access – Boston, US)
Stefania Serafin (Aalborg University Copenhagen, DK)
Benjamin Weyers (Universität Trier, DE)
Daniel Zielasko (Universität Trier, DE)

In the first working group session on "Accessible Tangible Games", several key points were discussed to enhance the accessibility and enjoyment of games for all players. The primary focus was on ensuring that games are not only usable but also easy, intuitive, and thus fun to play. This is crucial because, unlike other applications, people do play games for enjoyment. Therefore, the challenge lies in creating games that bring people together, regardless of their varying degrees of accessibility needs.

One of the central questions raised was the role of immersive technologies (XR) in making physical board games more accessible. The group debated whether XR is necessary or if traditional board game elements could be adapted to address broader accessibility issues. For instance, integrating aspects of board games into video games could make the latter more accessible. This includes synchronizing virtual and physical board states to ensure remote accessibility and using transitional interfaces like ego- and bird's-eye views. Additionally, smartphones could be employed for sonification and spatial audio, enhancing the gaming experience for players with visual impairments.

The discussion also touched on the nature of gameplay, considering both collaborative and competitive formats, concluding that collaborative formats avoid balancing issues of different interface types and thus might be the better choice to be considered further. The group highlighted the potential of Dungeons and Dragons (D&D) as a first use case, given its existing accessibility: Most parts of the game are imaginary and communities already address accessibility extensions such as Knights of the Braille[7].

Incorporating spatial audio, where players can hear their teammates talking on the board, was suggested as a way to create an inclusive, multimodal experience. This approach not only enhances gameplay but also offers opportunities for roleplay as part of therapy, benefiting disabled groups such as Knights of the Braille.

Finally, the group identified the need for further research and funding opportunities to support the development of accessible games. This includes surveying existing tools, identifying gaps in current systems, and exploring the potential of generative AI in creating customizable and inclusive gaming experiences. By addressing these challenges, the goal is to create games that are not only accessible but also enjoyable for all players, fostering a sense of community and inclusivity. Ultimately, the group identified possibilities for abstracting from board games to other scenarios re-using approaches for XR-based accessibility in case groups are collaborating on tasks, that incorporate a single physical space (such as a table).

In the second working group session, participants explored the integration of physical and digital elements to create inclusive gaming experiences. The discussion highlighted the potential of combining remote and in-person gatherings around a common scene, applicable not only to games but also to fields like architecture and urban planning.

Roles and Focus. The group identified key roles such as moderators, assistants, and users. They proposed focusing on games like Dungeons and Dragons (D&D), which are accessible to a wide audience. Tabletop systems like Roll20 and Tabletop Simulator were considered for their cooperative nature, which helps avoid issues of unfair advantages. The group emphasized the importance of starting from the perspective of blind or disabled individuals rather than sighted ones.

Tabletop Technologies. Various technologies were discussed to enhance accessibility. Visualization tools, AI-generated content, and support for Deaf/Hard of Hearing individuals through sonification were considered. For blind or low-vision users, sound effects, spatial sound, and soundscapes were suggested to indicate locations and create immersive experiences. Haptics and tangible objects, robotics, and proxy objects were also explored as input devices to assist remote players and those with motor impairments. The goal is to compensate for missing sensory channels and improve tabletop role-playing games (TTRPGs) for everyone, making them more accessible and enjoyable.

[7] `https://knightsofthebraille.com/`

Application Areas and User Groups. The group identified several application areas, including gaming communities, architecture and urban planning, military planning, search and rescue, digital twins, health outcomes, and education. They discussed the potential of gamification for exercise and therapy, highlighting how D&D can improve mental health. Medical planning, 3D design, and engineering were also considered relevant fields. Prototyping and Research Questions: The group brainstormed low-hanging fruit for prototyping, such as tokens that serve as AR tags and the use of spatial audio. Specific research questions included the sonification or enhancement of game elements for blind/low-vision players and identifying barriers that prevent disabled individuals from playing tabletop games. They emphasized the importance of consistent aspects like physical and virtual object operation, communication, and interaction between people gathered around a table, with remote attendance.

Current Implementations and Research. Examples of current implementations include chess sets that indicate pieces based on touch and board games for the visually impaired. The group reviewed research on tabletop game accessibility, such as exploring board and card gaming experiences of people who are blind or low vision, empowering soft skills in children with ADHD through co-created tangible tabletop games, and the benefits of D&D for college students and teenagers on the autism spectrum.

Outcomes and Next Steps. The session concluded with plans to write position papers on utilizing tangible games as a research platform for accessibility in XR. This includes conducting literature reviews, broad surveys, focus groups, and interviews. The group also discussed the need for software development to extend existing platforms and the importance of community organization, involving groups like AbleGamers, Knights of the Braille, and Limitless Heroics. They proposed defining student projects to create prototypes and organizing workshops at conferences like CHI Play and tabletop conventions like PAX Unplugged. The next steps involve stakeholder research, literature reviews, prototyping, and writing grants for further study, with potential breakout sessions at the XR Access Symposium.

4.3 Working Group on Low and High Hanging Fruits for Accessibility in XR

Bobby Bodenheimer (Vanderbilt University – Nashville, US)
Sarah Creem-Regehr (University of Utah – Salt Lake City, US)
Dylan Fox (Cornell Tech – New York, US)
Faustina Hwang (University of Reading, GB)
Tobias Langlotz (University of Otago, NZ)
Thies Pfeiffer (Hochschule Emden/Leer, DE)
John Quarles (University of Texas – San Antonio, US)
Daniel Roth (TU München, DE)
Richard Skarbez (La Trobe University Bundoora, AU)
Anthony Steed (University College London, GB)
Laura Trutoiu (Facebook – Redmond, US)
Khrystyna Vasylevska (TU Wien, AT)
Gregory Welch (University of Central Florida – Orlando, US)

In the working group session on "Low and High Hanging Fruits for Accessibility in XR," participants identified various strategies and challenges to enhance accessibility in extended reality (XR) environments. The discussion was categorized into three main areas: low-hanging fruit, mid-hanging fruit, and high-hanging fruit or grand challenges.

Low-Hanging Fruit. The group emphasized the importance of compiling lists of good accessible experiences and best practices. This could be achieved through a special issue of the Transactions on Applied Perception or a comprehensive review paper. A ten-year vision or roadmap was proposed to address significant accessibility challenges. The concept of "accessibility" in XR was explored, with a focus on industry-targeted, solutions-oriented approaches. Practical suggestions included developing Unity/Unreal "tagging" plugins for alt-text in VR, leveraging semantic tagging for VR art, and creating a taxonomy of restricted vocabulary. Experimental ideas such as Meta glasses inside head-mounted displays (HMDs) for real-time scene description and querying were discussed. The group also considered organizing workshops and lobbying at IEEE VR/ISMAR to raise awareness and convince the broader population of the importance of accessibility in XR. Additionally, experience reports and stories from XR Access and ASSETS were suggested to highlight different perspectives and user experiences.

Mid-Hanging Fruit. The discussion moved to more complex challenges, such as the lack of support for non-HMD displays in OpenXR. Encouraging the development of diverse hardware and adhering to W3C guidelines were seen as crucial steps. The group noted that while principles from web standards could apply to XR, specific techniques might not. Proposals included releasing an accessibility mode package for the Oculus Quest and supporting organizations that modify HMDs for users with special needs.

High-Hanging Fruit / Grand Challenges. The grand challenges focused on cross-reality accessibility, implying that XR should also enhance real-world interactions. The idea of a "magic chip" that recognizes everything in the environment was suggested. The afternoon session delved into XR Access resources, sharing stories at conferences like VR and ISMAR, and motivating researchers to prioritize accessibility. The group discussed the importance of standards, such as those from the Metaverse Standards Forum, to ensure institutional usability. They highlighted the need for accessible XR applications in healthcare, social life, and mobility, particularly for elderly populations. Overcoming user experience (UX) challenges and developing simple modes for ease of use were deemed essential. The potential of physical therapy as a gateway application and the role of AI in facilitating interactions were also explored.

The session concluded with a call for identifying key research gaps and securing funding. The importance of validating results with protected groups, conducting meta-analyses, and leveraging qualitative studies was emphasized. The need for copiloting and facilitating current headsets, which are not designed for partial operation by caretakers or experimenters, was highlighted. The group suggested reviewing current methodologies and exploring qualitative studies on how people engage with XR. They noted that social XR applications need significant improvements to justify their cost and complexity. Finally, the group discussed strategies for recruiting participants, navigating privacy and data protection challenges, and forming partnerships with organizations like Fable, Open Inclusion, and Lighthouse for the Blind.

4.4 Working Group on Non-Visual Interaction in XR

Dylan Fox (Cornell Tech – New York, US)
Katharina Krösl (TU Wien, AT)
Florian Lang (LMU Munich, DE)
Luciana Nedel (Federal University of Rio Grande do Sul, BR)
Steffen Puhl (Universität Gießen, DE)
Stefania Serafin (Aalborg University Copenhagen, DK)
Jeanine Stefanucci (University of Utah – Salt Lake City, US)

The working group session on "Non-Visual Interaction in XR" explored various facets of enhancing accessibility and inclusivity in extended reality (XR) environments. One of the discussions centered around the capabilities of scene weaving and the use of VR sighted guides. These technologies enable users to understand and navigate through virtual environments, which is crucial for creating a more inclusive XR experience. The group emphasized the necessity of establishing standards for non-visual interaction in XR, highlighting the importance of metadata and hooks for non-visual systems to ensure that solutions are not proprietary and can be universally applied.

The session also addressed the inherent challenges of VR as a predominantly visual medium. To overcome these challenges, the group proposed the development of multisensory interaction and representation of information to make virtual worlds more accessible. This includes the use of haptic feedback, where vibrations on different parts of the body can communicate various messages, akin to gestures in communication. Additionally, the integration of virtual assistants and the adjustment of sensory information to match the capabilities of users were discussed as essential components for enhancing non-visual interactions.

A significant point of discussion was the need for a hierarchical system to prioritize relevant information. For instance, an AI assistant should be able to differentiate between important and trivial details, such as identifying people in the room who can be spoken to versus describing every individual present. The group also explored the potential of selectively sonifying objects to indicate their size, velocity, and type, as well as their affordances, such as whether an object can be opened or interacted with. The working group underscored the importance of designing with users, not just for them, to ensure that the solutions meet the actual needs of those with sensory impairments. They referenced existing guidelines, such as the Game Accessibility Guidelines and the W3C's WCAG 3.0 draft, as frameworks to build upon. The group also discussed the potential for motion sickness with visual feedback and the potential to explore haptic and auditory interactions to mitigate this issue.

In conclusion, the session highlighted the necessity of creating inclusive XR environments by leveraging multisensory interactions and establishing universal standards. The group proposed a roadmap for understanding and implementing these standards, including consulting existing literature, running studies to investigate accessibility, and organizing workshops and calls for papers to foster innovation in this field. By focusing on both accessibility and inclusion, the group aims to create XR experiences that are immersive and accessible to all users, regardless of their sensory capabilities.

Further, the group prepared a workshop proposal for the IEEE VR 2025 conference, including a tentative Call for Submissions.

4.5 Working Group on Low Vision Interaction

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Sarah Creem-Regehr (University of Utah – Salt Lake City, US)
Katharina Krösl (TU Wien, AT)
Torsten Kuhlen (RWTH Aachen, DE)
Florian Lang (LMU Munich, DE)
Tobias Langlotz (University of Otago, NZ)
Steffen Puhl (Universität Gießen, DE)
Jeanine Stefanucci (University of Utah – Salt Lake City, US)

The working group on "Low Vision Interaction," discussed various strategies to raise awareness and improve accessibility for individuals with low or no vision. The group emphasized the importance of advocacy and collaboration with organizations dedicated to supporting these groups. One proposed approach is to engage in lobbying efforts by sending representatives to advocacy groups and inviting these groups to research institutions and conferences. Identifying key organizations in the USA and finding equivalent associations in the EU, such as the EuroXR Association, is crucial for fostering international collaboration.

The group also considered the potential impact of publishing papers that outline the issues and call for funding and research. Targeting high-impact journals like Nature or Science, as well as engaging in science news and podcasts, could help raise public awareness. Two types of papers were suggested: opinion pieces and research articles. Involving multiple disciplines and stakeholders, including industry partners, is essential for securing research funding and ensuring the practical application of findings.

Collaboration across countries, was discussed as a way to combine different perspectives on low vision as well as different approaches to increase accessibility. Tobias Langlotz work for example is focused on changing the visual appearance of the world to transform visual cues into perceivable ones for those with low vision, while Torsten Kuhlen is exploring the use of virtual agents as personal assistants. Bobby Bodenheimer focused on building better low vision simulations in head-mounted displays (HMDs) with eye tracking to understand real-world behaviors and deficits, and Katharina Krösl uses her low vision simulations primarily to increase empathy and understanding for people with vision impairments. Sarah Creem-Regehr emphasized the importance of understanding how low vision changes the visual information available for everyday tasks, suggesting that augmented reality (AR) could highlight crucial cues.

The group also discussed the potential of XR as a tool to help make the real world more accessible by identifying perceptual challenges. This can facilitate universal design, which aims to create environments usable by all people, rather than just inclusive design. In this context the group discussed whether some current technology follows a universal design approach and is accessible enough for low vision groups and whether devices are adjustable for different contexts. Drawing an analogy to hearing aids, they considered whether visual devices could be similarly fitted and adjusted via smartphone apps.

A significant research question emerged: What can be done right now with smartphones and AR to improve accessibility, and what problems need to be solved for always-on displays? Suggestions included using filters on displays to improve contrast, outline edges, or magnify content. The group noted that while voiceover functions on phones work well for blind users, holding both a cane and a phone can be challenging. Future devices could incorporate different controls and input methods to enhance usability.

Social acceptability and form factors were also discussed, with examples like Samsung glasses that resemble sunglasses but contain displays. The group concluded that developing devices with integrated sensors that are easy and quick to use is essential for mass adoption. Overall, the session underscored the need for interdisciplinary collaboration, innovative research, and practical solutions to improve accessibility for individuals with low vision.

4.6 Working Group on XR Taxonomy for Accessibility

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Faustina Hwang (University of Reading, GB)
Kiyoshi Kiyokawa (Nara Institute of Science and Technology, JP)
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Tabitha Peck (Davidson College, US)
Richard Skarbez (La Trobe University Bundoora, AU)
Anthony Steed (University College London, GB)
Khrystyna Vasylevska (TU Wien, AT)

In the working group session on "XR Taxonomy for Accessibility," participants explored various definitions and frameworks to enhance accessibility in extended reality (XR) environments. The session began by examining definitions from international standardization organizations. According to the ISO 9241-171:2008 standard, accessibility refers to the usability of a product, service, environment, or facility by people with the widest range of capabilities. This definition emphasizes that accessibility is not limited to individuals formally recognized as having a disability but addresses the full spectrum of user capabilities. The usability-oriented concept of accessibility aims to achieve high levels of effectiveness, efficiency, and satisfaction, considering the specified context of use.

The ITU's F.791 standard and the W3C's definition of web accessibility further elaborate on this concept. Web accessibility ensures that websites, tools, and technologies are designed so that people with disabilities can perceive, understand, navigate, interact with, and contribute to the web. These definitions underscore the importance of inclusivity and the need for accessible design in digital environments.

The working group identified several key outcomes or axes of accessibility, including actions such as access, navigation, interaction, and communication. These actions form the basis of a taxonomy of accessibility, which organizes the different aspects, types, or components of accessibility across various fields. This taxonomy helps structure the understanding of how accessibility can be applied to technology, services, environments, and products, ensuring inclusivity for people with disabilities or other barriers to access.

The taxonomy of accessibility can be broadly categorized into several areas:

Types of Disabilities: This includes visual, auditory, motor/mobility, and cognitive/neurological disabilities. Each type requires specific accessibility solutions, such as screen readers for visual impairments, closed captioning for auditory impairments, voice-controlled interfaces for motor disabilities, and simplified content for cognitive disabilities.

Digital Accessibility: This encompasses web accessibility, software accessibility, and mobile accessibility. Ensuring compliance with standards like the Web Content Accessibility Guidelines (WCAG), providing customizable user interfaces, and designing mobile applications with larger touch targets and simplified gestures are crucial for digital accessibility.

Physical Accessibility: This involves removing barriers in physical spaces, such as providing ramps, elevators, accessible signage, and wheelchair-accessible vehicles. Public facilities must also be designed to be accessible, with features like accessible restrooms and emergency exits.

Technological Accessibility: This includes the development of assistive technologies, such as hearing aids, prosthetic devices, screen readers, and eye-tracking systems. Ensuring that virtual and augmented reality technologies are accessible through inclusive design and haptic feedback is also essential.

Legal and Regulatory Accessibility: Compliance with accessibility laws and guidelines, such as the Americans with Disabilities Act (ADA) and Section 508, is critical. Ethical considerations must also be taken into account to ensure equality and fairness in accessibility.

Social and Economic Accessibility: Ensuring that products and services are affordable and widely available is important for social and economic accessibility. Designing solutions that are sensitive to cultural differences and language barriers is also necessary.

A well-structured taxonomy of accessibility provides a comprehensive framework for understanding, developing, and implementing inclusive designs and services across various domains. This approach ensures that accessibility is integrated into all aspects of XR environments, making them more usable and enjoyable for everyone.

4.7 Working Group on AI as Enabler for XR Accessibility

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Gregory Welch (University of Central Florida – Orlando, US)
Gottfried Zimmermann (Hochschule der Medien – Stuttgart, DE)

In the working group session on "AI as Enabler for XR Accessibility," participants explored the potential of artificial intelligence (AI) to enhance accessibility in extended reality (XR) environments. The discussion focused on several key areas where AI can play a transformative role.

Automatic Scene Interpretation and User Support. AI can significantly improve the accessibility of XR by providing automatic scene interpretation, answering questions like "What am I looking at?" and "What can I do?" This capability, akin to the "Be My Eyes" service, can help users understand their surroundings and interact with them more effectively. AI can also predict user intent and momentary discomfort, triggering appropriate mitigation strategies. For instance, AI can support natural interactions through verbal prompts or gestures and assist with movements such as navigating from point A to point B, opening doors, or manipulating objects with both hands. These functionalities can be built into applications or layered on top as additional services, utilizing self-describing interfaces and semantic context descriptions to enhance user experience.

User and Application Modeling. Effective AI-driven accessibility solutions require comprehensive user and application modeling. This includes understanding the user's biomechanical state, posture, and AI-computed characteristics. By modeling these aspects, AI can provide personalized support that adapts to the user's needs in real-time. The interaction between proactive and reactive AI, whether implicit or explicit, and whether initiated by the user or the system, is crucial for creating a seamless and intuitive user experience.

Natural Interaction in Virtual Communication. In virtual communication settings, participants have diverse capabilities and needs. AI can facilitate a natural interaction communication, allowing users to send and receive messages in any modality they choose, such as speaking, showing visuals, gesturing, typing text, signing, or any combination thereof. This extends the concept of "total communication", initially proposed by Gunnar Hellström and mandated by EN 301 549, by adding a "black box" that translates messages across different modalities, ensuring that everyone can communicate effectively. This raises important research questions about the representation of participants in social interactions. For example, should the embodiment of a participant indicate their communication needs, such as a blind person requiring verbal descriptions for visual presentations? Additionally, should messages be rendered on the participant's embodiment, or should a personal assistant provide necessary interpretations, such as sign language?

Future Directions and Research Questions. The session highlighted several future directions and research questions. These include exploring how AI can enhance the accessibility of XR environments through adaptive feedback based on individual and virtual context, and investigating the social acceptability and form factors of assistive devices. The potential for AI to support various applications, from gaming and education to healthcare and urban planning, was also discussed. By addressing these questions and leveraging AI's capabilities, researchers and developers can create more inclusive and accessible XR experiences for all users.

5 Outcomes

A variety of outcomes arose from this seminar. Here, we break them into categories that also represent future goals of the group and outcomes that are still in progress.

5.1 Steering Committee for XR Accessibility

We have formed a group that will persist in its advocacy for bringing awareness to issues surrounding accessibility with XR. The committee is made up of attendees who elected to be part of this organization initially for a workshop proposal review committee (see more on this below). However, the steering committee also has plans to advocate for making conferences more accessible to those with impairments or disabilities. There are plans to write letters to the organizing bodies of many of our interdisciplinary conferences (e.g., Association for Computing Machinery or Institute of Electrical and Electronics Engineers) in order to ask for more funding to support attendance at conferences and to generally bring awareness to issues surrounding accessibility with XR. We also will try to expand our steering committee to include people not in attendance at this seminar, but who may be interested in the topic of XR accessibility, such as members of the XR Access community who did not attend the seminar. One of our attendees (D. Fox) is the lead of this organization, so expansion of our group to include individuals from like-minded organizations is already underway. Further, one of our attendees (A. Olivier) is a General Chair for the IEEE VR 2025 conference. She is advocating for changes to accommodate accessibility for the conference. Finally, some members of the workshop who are located within the EU or the UK (led by A. Steed) plan to propose an Marie Curie innovative training network (ITN) on XR accessibility. We see this steering committee as an enduring outcome of the seminar that we hope will have wide-ranging effects on the community. We set up a Discord server for the seminar with various channels that we are now using to organize ourselves for further planning, along with the Dagstuhl Seminar email listserv.

5.2 Future Workshops on XR Accessibility

In order to introduce more researchers to ideas around XR accessibility, we have planned and proposed workshops at some of the major conferences for XR researchers. Specifically, a small group of us (led by B. Bodenheimer) proposed a workshop on XR Accessibility for the IEEE VR 2025 conference to be held in St. Malo, France from March 8th to 12th, 2025[8]. This workshop was accepted and it will feature stakeholder talks, poster presentations, and

[8] https://sites.google.com/view/xraccess/home

discussions around the topic of XR accessibility. The aforementioned steering committee will be reviewers for the submissions and seminar attendees are lined up to help with on-site organization of the workshop itself. Another workshop on XR accessibility is planned (by D. Zielasko) for submission to the CHI Play conference. Finally, one of our attendees (S. Stefania) is involved in organizing a conference next year (EAI ArtsIT) and has suggested featuring XR accessibility as special session at the meeting.

5.3 Papers to be published on XR Accessibility

The seminar resulted in many plans for future publications. Specifically, the working group on taxonomy for accessibility in XR realized that a larger paper with definitions and terms would likely be helpful for organizing the field. There was also recognition of a need for more papers and research discussing standardization of techniques for designing for accessibility. In order to aid in writing these types of overview papers, we set up a Zotero library of papers that was shared with all attendees of the seminar and can be made public to share with others who are interested in research in this field. A specific paper is planned that will discuss how to layout the design space for different types of sensory loss that is based on a paper already published on deficiencies in vision by attendee T. Langlotz. We believe that other papers will likely emerge as our group expands and attends workshops or conferences to further advance our ideas.

5.4 Ongoing Challenges

Despite the many outcomes that we are or have pursued thus far, there are challenges that we see in growing our advocacy and impact going forward. Ideally, we would like to secure some funding to continue to host meetings and seminars for those interested in advancing XR accessibility. Finding funding agencies that are interdisciplinary and also will work internationally to support groups is difficult. We have plans to talk to program officers in the United States in order to continue to pursue funding for meetings there. Some attendees are also pursuing an accessibility ITN as mentioned above. We also know that getting funding from organizing bodies in the XR field will not be easy. We will need to advocate heavily for more attention to be paid to accessibility as an issue for conference attendance, but also as a major topic worthy of research funding. Overall, we hope to use the steering committee and our growing community to continue to pursue these goals.

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