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Towards an Extended Perception Layer in Augmented Reality

Christian Murlowski
Saarland University, christian.murlowski@uni-saarland.de

Stefan Morana
Saarland University, stefan.morana@uni-saarland.de

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Christian Murlowski
Saarland University
christian.murlowski@uni-saarland.de

Stefan Morana
Saarland University
stefan.morana@uni-saarland.de

ABSTRACT

Augmented reality devices overlay digital content above our visually perceived real world and enable new ways of collaboration, communication, interaction, and perception. Extant research explores the conceptual foundations, technical prerequisites, and actual implementation of augmented reality in various domains. We lack a concept explaining the comprehensive range of digital layers in a holistic extended reality environment to understand how, when, and why users, for example, want to access or share information. This paper presents the extended perception layer (XPL) concept serving as the groundwork for users' interaction with augmented reality. The XPL concept describes the differentiation of three digital layers and suggests how accessing information, sharing content, and interacting with each other can be done within the layers. We contribute with the XPL concept and a corresponding research agenda to further explore the possibilities of augmenting users' visual perception.

Keywords

augmented reality; mixed reality; human-computer interaction; extended perception layer; research agenda

INTRODUCTION

The coalescence of reality and virtuality is a hot topic for major tech companies, such as the metaverse platform by Facebook (Meta, 2022) or Microsoft Mesh (Microsoft, 2022). From a conceptual point of view, this metaverse is "*the convergence of 1) virtually enhanced physical reality and 2) physically persistent virtual space. It is a fusion of both, while allowing users to experience it as either*" (Smart et al., 2007). Many related concepts exist for accessing such a metaverse, like augmented reality, mixed reality, and virtual reality, summarized under the term extended reality (Wohlgenannt et al., 2020). In contrast to the just mentioned definition, Rauschnabel et al. (2022) separate in their xReality framework between augmented reality, in which the physical environment is part of the user experience (local presence), and virtual reality, where an alternative digital reality (and not the physical environment) is part of the user experience (telepresence). We focus our research within this framework on augmented reality since we are interested in users' perceptions of digital and real environments.

A Goldman Sachs report (2016) saw the potential for the evolution of augmented reality and virtual reality technology to become a generic computing platform and be, therefore, as game-changing as the advent of the PC. Augmented reality provides the possibility to overlay digital content above our visually perceived real world. Thereby it enables new ways of collaboration and communication (Arashpour & Aranda-Mena, 2017; Yim et al., 2017), interaction (Hertel et al., 2021; Roo & Hachet, 2017), and perception (Rauschnabel et al., 2016; Stylidis et al., 2019). Individuals require appropriate devices to experience a digitally extended world. Since such devices are becoming more and more convenient and applicable, there is an increasing interest in the application of extended reality in various domains like medicine (Hilty et al., 2020), manufacturing (Doolani et al., 2020), and education (Pellas et al., 2020). Popular mobile devices like smartphones provide a see-through video solution when integrating augmented reality applications (Broll, 2022). Head-mounted devices like the Google Glass Enterprise Edition 2 or the Microsoft HoloLens 2 provide an optical see-through solution in which a ubiquitous digital layer coexists with our real world. Furthermore, a more natural reference to the real world is provided with head-mounted devices compared to mobile or stationary augmented reality solutions.

Seeing the real outer world overlayed with digital content simultaneously is a key feature of head-mounted devices for augmented reality. The displayed content is solely visible to the user and accessible within a digital layer. This functionality allows one to see information exclusively by oneself, share information with others (Mahmood et al., 2019), or share it with the public sphere (Vert et al., 2019). Although there is extant research on augmented reality, there is a conceptual framework missing that explains the comprehensive range of potential digital layers in a holistic extended reality environment. Such a framework can support researchers and practitioners in investigating how, when, and why users, for example, want to access or share information in augmented reality. To the best of our knowledge, no such conceptual framework exists that could serve as a foundation for research on this fascinating topic. To close this gap, we present the extended perception layer (XPL) concept serving as the groundwork for users' interaction with augmented reality. The goal of this paper is to describe the XPL concept and the differentiation of its three digital layers and suggest how accessing information, sharing content, and interacting with each other can be done within the layers. This paper contributes the XPL concept and a research agenda to further explore the possibilities to augment users' visual perception. First, we differentiate our work with reference to the current research area of augmenting devices. Afterwards, we provide a conceptual description of the XPL and usage cases for several layers. We describe a user scenario in which all layers are addressed based on a hypothetical real-life situation. Subsequently, we define several research avenues for the future development of the XPL.

CONCEPTUAL FOUNDATION

In the following, we provide an overview of the related terms that extend our perceptive views like augmented reality, mixed reality, and extended reality. Since the extended perception layer (XPL) refers to these technologies, this chapter provides a common understanding for our conceptualization. Further, existing concepts, their focus, and the need for an XPL in contrast to these concepts will be elaborated.

Terminological Differences

The concept of overlaying information on top of our perceived real world is not new. In 1901 the author Frank Baum proposed a spectacle that displays peoples' character properties on top of their heads with the help of a 'character marker' (Baum, 1901). Out of this fictional idea, it took several decades to develop a see-through head-mounted device, which allows users to move around within a room and see displayed 3D-Information and the real-world environment simultaneously (with some hardware restrictions) (Sutherland, 1968). Further, one of the first appearances of the term augmented reality was established by Caudell & Mizell (1992) while working on a prototypical head-mounted device in the context of aircraft manufacturing tasks and thus providing a practical approach for the usage of such devices.

Another term that is often used when encountering augmented reality is mixed reality. The term earned great attention within the virtuality continuum of Milgram & Kishino (1994), in which the real world and virtual objects coexist within a single display. It covers the area of technologies between the extrema of fully real or virtual environments. Although the virtual continuum provides a first classification attempt, augmented and mixed reality have not been used with a shared understanding or differentiation. Speicher et al. (2019) found multiple definitions in research, e.g., augmented reality is part of mixed reality as in the virtual continuum, using both terms synonymously, seeing mixed reality as a collaborative notion, or understanding mixed reality as a combination of augmented and virtual reality.

In the past years, the term extended reality refers to "… all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables" (Fast-Berglund et al., 2018). It is often seen as an umbrella term that comprises technologies from augmented to virtual reality (Wohlgenannt et al., 2020). While it seems easy to use extended reality for the whole range of these technologies, it faces problems like comprising the term virtual reality. However, virtual reality does not describe an extension of reality but replaces it with an alternate reality (Rauschnabel et al., 2022). Therefore, the xReality framework of Rauschnabel et al. provides a clear distinction between augmented reality (the user can experience the physical environment) and virtual reality (no reference to the physical environment is given). Since we focus on a digital layer that overlays our experience of the physical environment and is not altered by a comprehensive virtual environment, we focus our research on the augmented reality continuum of the xReality framework.

Independent of the ongoing debate regarding terminological differentiation, we focus on describing an XPL concept that implicitly comprises the stated terms regarding the perception of different extensions of the physical reality. Despite the differences in understanding the terms, they have one thing in common: In some way, digital elements overlay or coexist with the users' perceived real world. Therefore, technologies like augmented or mixed are part of or contribute to the XPL.

State-of-the-art Conceptualizations

The extension of human performance and capabilities has been investigated for decades (Lawson, 2014). For example, De Boeck & Vaes (2021) classify human augmentation by differentiating between sensory, physical, cognitive, and social augmentation. This framework provides interesting insights into how human abilities can be replicated, supplemented, or exceeded for our research approach. Our focus is the extension of humans' visual perception, for example, with head-mounted devices. Thus, we consider only a subset of De Boeck & Vaes's classification to avoid an overcomplex XPL conceptualization.

With the rise of augmented, mixed, and virtual reality devices, multiple concepts have been developed to provide a distinction and understanding of technologies. One of the first approaches for differentiating mixed reality display systems is known by Milgram & Kishino (1994). Besides their virtual continuum, in which several technologies can be classified, they state three dimensions that differentiate several mixed reality display systems from each other. These dimensions include the extent of world knowledge (i.e., knowledge a display device has about the shape and location of objects), reproduction fidelity (i.e., quality of objects or images being displayed), and extent of presence metaphor (i.e., the extent to which human feels present within the displayed scene). A more recent conceptual framework for mixed reality displays has been developed by Speicher et al. (2019). After analyzing the results of expert interviews and a literature review, they defined five

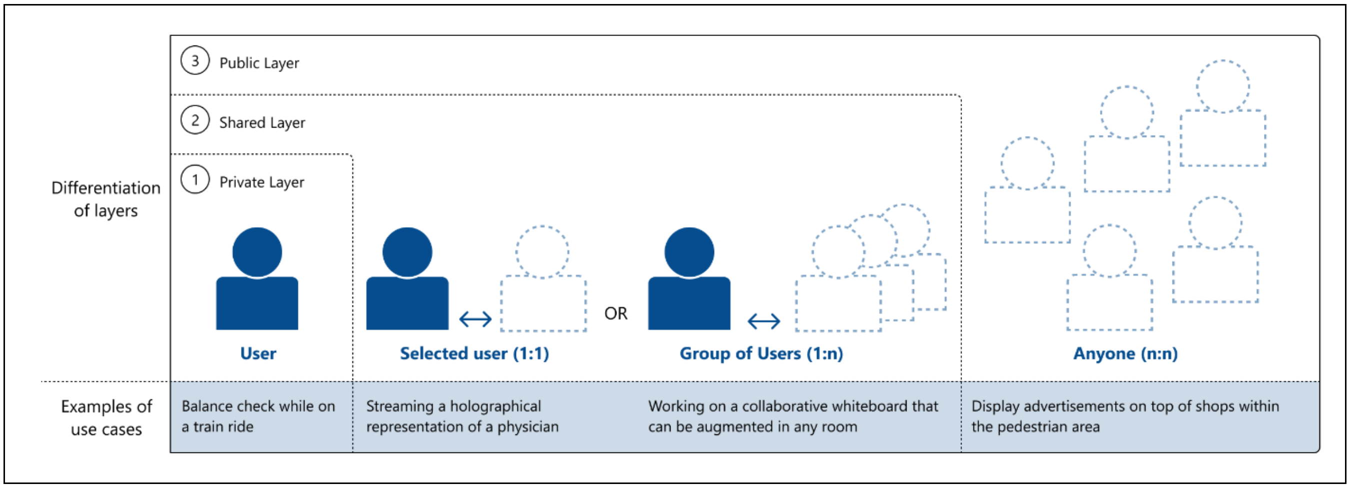

Figure 1. The extended perception layer (XPL) conceptualization with a private, shared, and public layer

main dimensions (number of environments and users, level of immersion and virtuality, and interaction) and two lower dimensions (input and output modalities) to clarify the meaning of mixed reality in a specific context. While both concepts are fundamental, they also consider virtual reality experiences. Since we focus on augmented reality experiences, virtual reality is out of scope and should be handled separately because of its missing relation to physical reality.

In their xReality framework, Rauschnabel et al. (2022) explain the term xReality and separate augmented and virtual reality, based on whether the physical environment is, at least visually, part of the experience or not. Within the augmented reality continuum, the authors define a range of local presence with assisted reality on the one end of the extrema (e.g., digital content is placed as stable content above the real environment) and mixed reality on the other end (e.g., digital content is integrated and coexists within the real environment). Since the physical environment is of interest to our conceptualization, the augmented reality continuum works with the understanding of technological differentiation. We use this framework as a baseline for classifying our concept while considering augmented reality experiences and excluding virtual reality experiences. Further, we focus on the range of overlaying and coexisting digital elements and the local physical environment.

We face a general issue by inspecting the mentioned frameworks: their focus on classifying terms and differentiation of technologies or hardware. When looking at the terminological differentiation and already established concepts, two key aspects must be considered during the development of the XPL concept: First, we do not focus on specific terms and classifications of these. However, we want to provide a conceptualization of a digital layer that a user ubiquitously experiences. While several technologies like augmented reality and mixed reality already comprise such possibilities, we are not considering virtual reality since users experience an alternative virtual world, and no reference to the actual physical world is given. Second, our contribution to the research field of augmenting technologies focuses on the individual user's perspective and the extension of the user's perception. A new form for accessing and sharing information has evolved with augmented technology. These technologies provide the opportunity for a new experience by augmenting our perceptive visual field. Further, the ability to collaborate with other users or interact within a private layer is given. Therefore, we present the conceptualization of the extended perception layer next.

TOWARDS AN EXTENDED PERCEPTION LAYER CONCEPT

The development of the extended perception layer (XPL) concept is based on the extension of the user's perception of displayed information and interaction with other users. Our layer concept is oriented towards real-life scenarios on how we consume information by ourselves, share it with dedicated people, or disclose it to the public space. Multiple layers exist in which users can participate. We define three layers within the XPL that describe the interaction from the users' perspective (see Figure 1): private layer, shared layer, and public layer. We provide an overview of these layers with examples of how users interact with them and potential use cases for each layer.

The **private layer** describes all single interactions and sharing of information of a single user with augmenting devices. Only the user perceives the information displayed on this private layer. This private layer can be used, for example, for sensitive information such as checking the bank account. This use case requires personal and private information that should not be shared with other people or disclosed to the public.

Besides the usage or interaction with information within a private layer, some information is worth sharing with other users on a **shared layer**. Therefore, the shared layer describes a user's interactions with at least one other dedicated user (1:1) or a group of users (1:n). This layer represents a collaborative place shared with selected people or a group of users to work together on tasks or distribute information to these users. Therefore, the information flow is bidirectional. This layer is beneficial, for example, for sharing private information with selected users or working collaboratively on tasks. One example of a user-to-user interaction could be the holographic representation of a physician and the simultaneous sharing of relevant information from body sensors in a telemedicine consultation session. In addition, one example of user-to-group interaction in the shared layer could be working on a collaborative whiteboard or holographic prototype in any location or superimposing magnetic resonance imaging over a patient during surgery to guide the treatment.

The **public layer** describes all interactions of a single user or a group of users with the public audience and vice versa (n:n). It is an open and ubiquitous space where information can be placed, shared, and received by anyone with access to the public layer. There are several ways how to access information in this layer, such as location-based information that is perceived at the point of interest of the user (e.g., the leaderboard of a running session at a specific place or advertisement of a shop), urgent information that is displayed directly in the view of the user (e.g., a governmental risk warning), or publicly available information that the user must actively access (e.g., a news feed).

To better understand the differences between these layers and how users interact with the proposed XPL, we provide a real-life scenario based on the specific use case of handling health data in the following. Therefore, we consider the user Alex to be working in a full-time office job and wearing an augmented reality head-mounted device. She tracks her health status like heart rate, workout activities, and sleep with a smartwatch during her everyday life. Alex wants to inform herself about her vital status. She is actively looking for her sleep activity of the last night and her workout activity in the past few days on the *private layer*. Because of a recent injury, she reports her sleep activity and vital data weekly to her physician throughout her medical treatment. Alex and her physician conduct a telepresence session. One person is displayed as a holographical representation of the other person's display within the physical location. Within the *shared layer*, the physician can discuss the results and show Alex appropriate exercises for her workout plan to support her recovery. Alex would like to participate in a monthly running event publicly available in an urban park. Therefore, she walks to the starting point of the location displayed on the head-mounted device, registers with her data, and can start the running session. She shares her running speed, duration, and pace with anyone in the *public layer* during the run.

RESEARCH AGENDA

Our extended perception layer (XPL) conceptualization addresses the need for a framework to investigate the possibilities of digitally overlaying information above users' perception of the real world. Since other frameworks or models define terms or classifications of devices, the possibilities for users with a ubiquitous digital layer have not yet been in focus in recent discourse. Although we provide an initial conceptualization of the XPL, it represents only a starting point and must be further explored. Therefore, we propose an initial research agenda for further investigation based on our conceptualization of the interaction and perception in the XPL. The research avenues and proposals are summarized in Table 1.

The first avenue of research compromises the **extension and refinement of the XPL**. Based on our understanding and selected literature, the current underlying conceptualization of the XPL explains the perception and interaction from the user's viewpoint. Nevertheless, the foundation of the concept should be extended with existing theories and concepts. Moreover, we believe the conceptualization would benefit from conducting interviews, focus groups, or observations with stakeholders from various application domains. Potential users would help understand the current need for such devices and specific use cases implemented in the three layers. For example, teachers might have different use scenarios as employees in manufacturing, given their different working contexts. Practitioners could provide insights about how they would like to use augmenting devices for their business and how they would like to address their target group. Moreover, scholarly experts could provide more theorized input and insights. All of them provide a valuable contribution to the XPL. In addition, testing augmented reality prototypes in lab-based, and in-the-wild approaches would benefit the refinement and extension of the XPL.

The second avenue of research addresses the **acceptance and adoption** of applications running in the XPL. A key factor for the success of innovations is the acceptance and adoption of the technology (Venkatesh et al., 2012). Several drivers exist regarding the usage of augmented technologies for the acceptance and adoption of devices like utilitarian, hedonic, and symbolic benefits (Rauschnabel et al., 2018). The use cases elaborated in our concept describe the differentiation, and the use of our three layers is based on approaches reported in literature (Hilty et al., 2020; Mahmood et al., 2019; Schmalstieg et al., 2000). However, they have been established theoretically and must be empirically tested in real-world scenarios. Further, the view of companies for using augmenting devices should also be considered regarding their motivation to use such devices for extending the business portfolio as well as extending or joining a market. Therefore, several use cases should be investigated in further studies regarding the motivation of users as well as companies for technological acceptance and adoption of applications utilizing the different layers within the XPL.

Research Avenue	Exemplary Research Proposals
(1) Extension and Refinement of XPL	▪ Investigate theories and conceptualizations that provide helpful input for refining and extending the XPL concept. ▪ Conduct interviews, focus groups, or observations with stakeholders from various domains to refine the XPL concept and identify relevant use cases. ▪ Explore practical use cases for the XPL concept to gain more insights into how the three-layer concept can be enhanced.
(2) Acceptance and Adoption	▪ Investigate the application and extension of existing acceptance and adoption theories for the XPL. ▪ Explore additional factors driving the acceptance and adoption of applications running in the XPL in lab and field studies.
(3) User's Trust	▪ Identify the current state of research regarding users' trust while using augmenting devices. ▪ Explore factors that influence users' trust within different layers of the XPL from a technological point of view. ▪ Explore factors that influence users' trust with other users when interacting in the shared or public layer of the XPL. ▪ Investigate the enhancement of users' trust in augmented reality hardware and applications.
(4) Interaction Modalities and User Experience	▪ Identify interaction modalities for augmenting devices and how they can be adapted to the XPL. ▪ Address usage scenarios with a focus on the design of appropriate interaction modalities. ▪ Investigate how existing design principles and guidelines can be reused to design applications for the XPL. ▪ Explore factors that must be considered regarding the user experience while using an augmenting device.
(5) Augmentation of Human Abilities	▪ Investigate different technologies and devices that can extend the abilities of humans and extend the XPL concept. ▪ Explore the inclusion of other human senses (i.e., hearing, touching, smelling, tasting) into the conceptualization of the XPL.

Table 1. The research agenda for the extension and refinement of the XPL

A third avenue of research focuses on **users' trust** within the different layers and applications running on these layers. In addition to accepting and adopting emergent technologies in a specific context, users must trust the technology. There are concerns regarding the usage of augmented reality devices, like privacy risks of users themselves (e.g., unwanted access to sensible data) and others (e.g., screening and processing of the surrounding by head-mounted devices) or losing autonomy (e.g., little or no control over the actions while using the technology) (Rauschnabel et al., 2018). Since the XPL describes several layers for the interchange of users, further research should focus on the users' concerns regarding trust issues and how to build trust with the utilized technology, and the other users interacting in the XPL. In particular, interaction with other users in the shared or public layer requires further research, especially concerning factors that drive users' trust in interacting with each other. Furthermore, several companies are becoming significant drivers in developing more convenient devices and establishing a ubiquitously digital world, such as the metaverse. As seen by major social platforms with a large user basis, questions regarding using private or sensitive data arise. With a ubiquitous digital layer, concerns regarding the processing and usage of private data or monitoring of users could also lead to trust issues (De Guzman et al., 2020).

The fourth avenue for research on the XPL explores **interaction modalities and the user experience**. Technology advancements lead to different interaction methods for users with augmented reality devices. Several ways to interact with such devices exist, like controllers, gaze input, or hand gestures (Hertel et al., 2021). Looking at the XPL, some use cases could benefit more from one interaction method than another. For example, a controller could be beneficial in a school class for easier interaction to observe a physical phenomenon. However, a controller would not be the appropriate interaction device during the repair session of a car, holding tools in both hands and looking for the following item to release. Future research should focus on which interaction techniques within the XPL are helpful in specific contexts.

Users' direct interaction with the user interface and the overall user experience play an essential part in the interaction within the XPL. The interface provides the user with possibilities to interact with the application and environment. Appropriate devices and applications provide the foundation for a good user experience. Guidelines for interactions and developing a good user experience exist (ISO, 2022; Nielsen, 1993). We suggest that future research should focus on designing a user interface for the respective technology. Existing interaction paradigms and UX guidelines have to be investigated if they still hold with the usage of the XPL and if they have to be changed or further developed.

The fifth avenue of research investigates the **augmentation of human abilities**. We currently focus on the user's visual sense while interacting with augmented devices. However, four more senses (listening, smelling, tasting, or touching) can augment our perception. While most of the research regarding augmenting devices focuses on perceptual, other senses have not been investigated in similar depth because hardware manufacturers focus on the user's field of view (Chuah, 2019). Besides sensory augmentation, some systems augment humans' physical, cognitive, or social abilities (De Boeck & Vaes, 2021). Whereas physical augmentation provides enhancements like prostheses or exoskeletons, cognitive augmentation systems help improve memorizing or optimize the learning experience, for example, for medical students by easily showing a cross-section of body parts. Social abilities could be enhanced, for example, with lighting hardware that expresses the feelings of humans or augmented reality devices for working within a collaborative digital room. Future research could investigate how other human senses than the visual and required technology could be integrated into the XPL and how our framework can be refined.

CONCLUSION

This paper provides a theoretical conceptualization of the extended perception layer (XPL) using augmented reality technology. Currently, existing research focuses on classifying terms like augmented, mixed, or virtual reality and their differentiation. While this is important for building a shared understanding for research, practice, and end-users, our focus lies on a single user who is ubiquitously experiencing a digital layer augmenting their visual field of view with digital objects. Further, related research considers a wide range from augmented reality to virtual reality devices. We focus on the interplay of digital objects and the real world with various devices that extend the user's visual perception. This focus lowers the complexity of considering a broad spectrum of devices and extended reality concepts. Lastly, augmenting devices provide new possibilities for accessing and sharing information with users themselves, other users, or the public. Therefore, we focus on the user's perspective while interacting with augmenting devices. We propose a layer concept with a private, shared, and public layer enabling the access and sharing of information and interaction with others. This research-in-progress paper elaborates a research agenda to investigate the refinement and extension of the proposed XPL concept. Moreover, the research agenda includes exemplary proposals for future studies addressing various aspects of the concept to augment users' perceptual views.

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