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Cues to fast-forward collaboration: A Survey of Workspace Awareness and Visual Cues in XR Collaborative Systems

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Abstract

Collaboration in extended reality (XR) environments presents complex challenges that revolve around how users perceive the presence, intentions, and actions of their collaborators. This paper delves into the intricate realm of group awareness, focusing specifically on workspace awareness and the innovative visual cues designed to enhance user comprehension. The research begins by identifying a spectrum of collaborative situations drawn from an analysis of XR prototypes in the existing literature. Then, we describe and introduce a novel classification for workspace awareness, along with an exploration of visual cues recently employed in research endeavors. Lastly, we present the key findings and shine a spotlight on promising yet unexplored topics. This work not only serves as a reference for experienced researchers seeking to inform the design of their own collaborative XR applications but also extends a welcoming hand to newcomers in this dynamic field.

CCS Concepts

• ***Human-centered computing*** → *Mixed / augmented reality; Virtual reality;* ***Collaborative interaction;***

1. Introduction

In the dynamic realm of digital technology, the blend of extended reality (XR) and collaborative environments has brought about a new era of work, communication, and interaction. XR technologies encompass a spectrum of immersive experiences, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), where physical and digital worlds seamlessly coexist. Within this context, the concept of Workspace Awareness (WA) introduced by Gutwin and Greenberg [GG02] takes on profound significance, particularly when enriched and augmented by the use of visual cues.

Workspace awareness in the context of XR extends far beyond conventional notions of physical and digital workspaces. It encompasses an individual's cognitive understanding of the spatial, environmental, and collaborative elements in XR spaces. Visual cues within XR, including spatial symbols, virtual representations of collaborators, and augmented environmental overlays, play a crucial role in enhancing workspace awareness. This augmentation significantly influences how individuals connect, interact, and collaborate in virtual and augmented realities, making it a topic of paramount importance for diverse domains [SWB*22], including education [NI11], healthcare [PEK*21], industrial assembly [OES*15], and entertainment [PT02].

This chapter explores the interplay between workspace awareness and visual cues, within the immersive landscape of the extended reality spectrum, and its pivotal role in reshaping collaborative environments.

1.1. Collaboration and Awareness in XR

Immersive collaboration is gaining traction in the field of Computer-Supported Collaborative Work (CSCW) [ACGN23], which is the study of individuals working together using computer-based tools such as groupware. It is noticeable that designing systems with interactive multiple-user support is even more relevant in recent days in a world post-pandemic when more individuals are working and communicating, synchronously or asynchronously, in different places and time zones.

One example of the many benefits of collaborating in XR is presented by [Wol19]. The research findings highlight the effectiveness of the VR approach in actively involving a larger number of professionals in the review process of intricate 3D models from an engineering standpoint. Additionally, the immersive features of VR facilitated the detection of a higher number of flaws within the project, further underscoring its advantages in this context.

Exploring the fusion of AR and VR in an asymmetric collaboration setup is an intriguing area of study, as evidenced in various research papers [PLLB17, PDE*19, PLI*19, RTM*20, GDM19, WBB*20a]. These investigations aim to devise intuitive methods for interaction, fostering seamless cooperation among users utilizing diverse immersive technologies. Furthermore, they underscore the significance of enhancing user awareness through the integration of visual cues to enrich communication channels between these users.

Awareness is a multifaceted concept that pertains to an individual's understanding of their collaborators, the shared workspace, and the ongoing activities within that workspace. It enables effective communication which is a process of exchanging important and clear information between collaborators so they can perform tasks together.

Some studies aimed at defining and classifying all types of awareness. According to Schmidt [Sch02], awareness may not be considered a product of passively acquired information but a highly active mechanism. It provides collaborators with important information like users' availability, state of progress, and many other details [LG17]. Also, it is described as the "knowledge that a person has of the activities that other people were collaborating with him/her are performing" [DB92]. This knowledge can happen at the moment of another's user interaction in a shared workspace.

For Mantau and Benitti [MB22], awareness is the state of being conscious of something. The authors conducted a systematic mapping study to analyze the design, development, and evaluation of groupware systems with a focus on awareness and collaboration concepts within the field of CSCW. The study encompassed the last 10 years of CSCW publications and identified 92 awareness elements or widgets, organized into 17 design categories, addressing the five primary dimensions of awareness, which are contextual, collaboration, situational, workspace, and historical.

An additional study [AHOP14] categorized awareness within an application based on time, place, and space. To elaborate further, they differentiated and assessed six distinct types of awareness, encompassing collaboration, location, context, social, workspace, and situation awareness.

This paper focuses on workspace awareness, a concept presented by Gutwin and Greenberg [GG02] that is presented in the next section. We consider it relevant because it empowers individuals and organizations to work together more efficiently, overcome the challenges of distributed work, and solve complex problems. Its applicability across various fields makes it a foundational concept for shaping the future of collaborative work and interaction.

1.2. Workspace Awareness

Workspace Awareness, as proposed by Gutwin and Greenberg [GG02], is a framework that encompasses an individual's cognitive perception of a shared workspace in a real-time groupware environment. This perception is not limited to a mere awareness of the presence of collaborators but extends to a nuanced understanding of the context in which these collaborators are operating. It includes knowledge about who is present, what they are doing, and the environmental conditions of the workspace. Essentially, it provides a mental model that enables individuals to make informed decisions, coordinate activities, and effectively engage with their peers.

The conceptual framework introduced distinguishes itself from prior groupware awareness studies in three notable ways: First, it combines and builds upon existing observations and awareness theories. Second, it focuses on a specific scenario involving small groups collaborating within medium-sized shared workspaces. Lastly, its primary objective is to support the iterative design of real-time distributed groupware systems.

Thus, the framework for workspace awareness revolves around three fundamental aspects: understanding the types of information individuals monitor in shared workspaces, examining the methods through which workspace awareness information is acquired, and exploring the ways in which individuals leverage workspace awareness data during collaborative activities.

It is essential to mention the constraints this framework has on some collaborative situations, which are contexts in which individuals work together towards a common goal. Those situations are:

- Real-time distributed groupware: people can work or play together at the same time but from different places.
- Shared workspace: flat, medium-sized surfaces.
- Generation and execution tasks.
- Small groups and mixed-focus collaboration.

In summary, the authors define workspace awareness as "the up-to-the-moment understanding of another person's interaction with the shared workspace". It is the awareness of individuals and how they interact with the workspace.

1.3. Visual Cues

Visual cues (VC) play a pivotal role in shaping the immersive collaborative environments of today. These cues encompass a range of visual elements and signals that provide users with vital information about their surroundings, the presence and actions of co-collaborators, and the overall context within which they are operating. In essence, visual cues serve as the bridge between the physical and digital worlds, enhancing users' understanding and engagement within these immersive spaces.

One good example of visual cues would be the virtual representations of collaborators, often in the form of avatars. They offer users a sense of presence and awareness of the participants within the immersive environment. These representations facilitate identification and communication with collaborators, thus fostering a more engaging and social experience in the virtual world.

It is noticeable that in immersive environments, individuals lose some natural abilities to communicate non-verbally. Still, XR technology presents a unique opportunity to explore and improve collaboration by featuring user awareness. Designers can develop visual cues and blend them digitally, helping users be aware of other collaborators' intentions or actions.

1.4. Method

We conducted a systematic mapping study in the last 10 years to find collaborative prototypes in the XR spectrum. The exploration commenced by querying the Scopus database, employing keywords such as awareness, collaboration, cues, extended reality, virtual reality, augmented reality, and mixed reality. This approach yielded an initial pool of 47 papers deemed potential candidates for inclusion in our analysis.

To ensure the relevance and specificity of our findings, a thorough review was undertaken, leading to the exclusion of 36 papers that predominantly centered on audio cues, haptics, games, or those lacking a distinct focus on workspace awareness. Following this curation process, our final selection comprised 11 papers that emerged as pivotal contributions to understanding visual cues and user awareness within the XR spectrum.

We established a comprehensive coding framework for the selected papers. The framework encompasses key dimensions such as groupware characteristics, group size, visual cues and awareness descriptions, environment size, and collaboration task types. This systematic approach forms the backbone of our information extraction process, playing a pivotal role in realizing the objectives of this systematic mapping study.

To enhance the reliability and consistency of our coding, active involvement from all authors was ensured throughout the process. This collaborative effort guarantees a unified application of the coding framework, reinforcing the integrity and accuracy of the findings.

We also performed a snowball technique to improve the reviewing data. We looked for relevant XR conferences, such as the IEEE Conference on Virtual Reality and 3D User Interfaces and the ACM Symposium on Virtual Reality Software and Technology. We then collected 53 papers from the mentioned time frame and applied the coding framework. With that, we ended up with more 32 papers to assess their user awareness, visual cues, and collaborative situations.

In crafting our classification system, we initiated a comprehensive discovery phase. This involved systematically compiling all instances of user awareness identified within the papers under consideration. Subsequently, we engaged in the process of categorization, grouping together similar awareness concepts and refining them into more generalized definitions. Simultaneously, we recognized visual cues linked to each awareness type and combined them into broader categories to cover a wider variety of scenarios. This iterative process ensured a nuanced and inclusive classification system tailored to the varied dimensions of user awareness and visual cues present in the literature.

1.5. Objectives

This paper primarily aims to explore recent research findings concerning how users perceive one another in XR collaborative systems, focusing on categorizing these perceptions based on collaborative situations that influence user behavior and their overall immersive experience. We didn't focus on incorporating audio or verbal cues; rather, we are dedicated to examining visual cues and the intricacies surrounding workspace awareness. Moreover, we have introduced a unique classification system that takes into account user awareness based on both workspace awareness and the associated visual cues.

The proposed classifications provide a structured framework for researchers and practitioners to categorize and analyze different aspects of awareness. This classification serves as a foundation for studying and designing XR systems and technologies related to awareness in various domains. We hope that researchers can use this work as a guide to help design their own collaborative XR applications or even contribute to expanding the proposed classification. We also expect to help newcomers in the field grasp the key concepts and approaches to handling awareness in XR and its related visual cues.

We also understand that workspace awareness augmented with visual cues is essential for promoting effective collaboration, reducing the challenges of distributed work, and enhancing the design of collaborative tools. As XR work environments continue to evolve, the concept of workspace awareness remains a cornerstone for creating more efficient and satisfying collaborative experiences in the digital age.

In the following section, we present the proposed classifications, beginning with the collaborative situations and their characteristics. Then, we start a topic about user awareness and divide it into two sub-topics. The visual awareness cues, which are graphical representations used to help raise awareness from other collaborators during tasks, and the awareness types users might get from others. Last, we discuss the findings exposing unexplored topics relevant to future work.

2. Taxonomy

In this section, we introduce a fresh classification of XR collaborative situations that impact the dynamics among collaborators. Following this, we provide an overview, detailed descriptions, and nomenclature for the awareness visual cues identified in the surveyed literature. Finally, we establish associations between these cues and the specific awareness types they serve, elucidating their intended purposes.

2.1. Collaborative Situation

A collaborative situation is a context in which individuals work together towards a common goal, sharing information, resources, and tasks to achieve that objective. This concept is central to the exploration of user awareness, as it pertains to understanding how individuals maintain awareness of the workspace and their co-collaborators while engaged in collaborative tasks within such contexts.

Following an extensive review of XR applications in the literature, it became evident that users often employ diverse strategies for navigating, visualizing, and collaborating in virtual environments according to a certain situation or context. For instance, a platform might facilitate synchronous collaboration, enabling real-time interaction among users, while an alternative design choice could introduce asynchronous features, resulting in a distinct user experience and tools. As a result, we have categorized and emphasized eight fundamental situations within collaborative XR applications.

- **Visualization Scale:** This feature illustrates the presentation of the virtual environment in terms of its dimensions and how users perceive it, all contingent on the specific goals and intentions of the application.
  1:1: Virtual objects are shown on an accurate scale in which users collaborate and interact in natural dimensions. It is a common practice in virtual reality applications for architecture and construction where engineers or potential buyers can accurately perceive the space and the environment. Nevertheless, precise scene scale representations may impact when a user needs

Table 1: *Collaborative Situation*

Feature	Properties		Papers
Visualization Scale	1:1		[CSF20]
	Resized		[PLI*19]
Environment	3D		[TLBA19]
	360 Panorama	Live	[THL*19] [LTKB17] [JMN*21]
		Static	[TLBA19]
	360D		[TLBA19]
Space	Remote		[FKIA20] [WBB*20a] [HKBA19] [SDM*19] [MSKB16]
	Co-Located		[CLL*21]
Time	Synchronous		[WKF19] [PDE*19] [PLLB17] [XHPW18]
	Asynchronous		[ISVI*16]
POV	Egocentric		[XHPW18]
	Exocentric		[RH17]
Setup	Symmetric		[XHPW18]
	Asymmetric		[RH17] [PDE*19] [PLI*19]
User Position	Free		[RH17] [PDE*19] [PLI*19] [XHPW18]
	Constraint	Face to Face	[SMD*19]
		Side by Side	[SMM*17] [SDM*19]
		Other	[WF21]
Role Symmetry	Symmetric		[XHPW18]
	Asymmetric		[WF21] [PLI*19]

to overview the scene environment quickly. It may be time-consuming to find occluded objects or search for something in a 1:1 scale scene that can be vast.

Resized: The scene is represented on a smaller scale, making it easier to get a global vision, or on a bigger scale, enhancing the details of an object. Therefore, manipulating a scene's size helps find the desired information that could be occluded or distant. According to [DEJW21], World in Miniature, a technique that resizes a scene to a smaller scale, is frequently used in data visualization for overview and detail goals. Also, [KNBP06] proposed changing the scale of objects automatically, allowing content viewing to be more comfortable for users.

- **Environment:** The virtual scene that makes up the environment can be built with different kinds of data listed in this topic. Some of them are faster to be developed but lack more details, such as depth information. So, it is essential to know the limitations and strengths of each technique to design a collaborative system.

3D: 3D digital assets rank among the most prevalent data types for constructing virtual environments. They possess the ability to replicate reality by employing physically-based shaders and lifelike textures through real-time rendering engines. While the creation of such assets may demand considerable time during the production phase, especially concerning the development of realistic shaders, they offer invaluable benefits. 3D assets introduce depth perception and afford users the freedom to navigate through the scene without constraints.

360 Panorama: One alternative to a 3D pipeline would be using a 360 video or image for displaying the environment. The footage is generated by a special camera that unwraps it in a 3D sphere to simulate the landscape. This technique can be streamed live or used as a recorded video file. Although this could be a faster workflow to produce high-quality virtual scenes, 360 panorama lacks depth perception. It signifies a not-so-good user experience to walk through the scene or create annotations in specific areas. One study [LTKB17] presented an MR remote collaboration system that allows sharing a live captured immersive panorama with visual cues to help the users understand each other's view direction.

360D: Last, we found a hybrid method known as 360D, which combines 360 panoramas into a 3D scene to introduce a novel way for users to interact and collaborate. According to the authors of this study [THL*19], combining 360 panoramas and 3D scenes offers remote users more options to access the local user's environment, allowing more variations to solve tasks in a collaborative environment.

- **Space:** It is a dimension of the traditional time-space matrix [Bae94]. Collaborating with other individuals doesn't necessarily mean sharing the same physical place. Therefore, this feature indicates the physical location of users using the same system.

Remote: Indicate that users collaborate in different physical locations.

Co-located: Indicate that users share the exact physical location.

- **Time:** This dimension denotes the instant collaboration among users using the system.

Synchronous: Collaborative information is sent and delivered instantly to all users in real-time. It allows individuals to communicate with each other when they are using the system at the same time.

Asynchronous: Collaborative information is sent and delivered on the collaborative system, but others only access them later when they log into the system. It does not require collaborators to use the system at the same time.

- **Point of view (PoV):** The user's point of view indicates how individuals view the digital scene. This feature may impact the perception of self and embodiment.

Egocentric: The user's point of view comes from their own eyes.

Exocentric: The user's point of view is different from their eye's perspective.

- **Setup:** This feature is related to the blend usage of different levels of the virtuality continuum. Collaborative systems, in this case, may use identical or nonidentical setups to engage users' communication.

Symmetric: When both users collaborate at the same range of the virtuality continuum. Ex: VR-VR or AR-AR.

Asymmetric: When users collaborate at different ranges of the virtuality continuum. Ex: VR-AR.

- **User Position:** It represents the virtual position and the limits of the user movements inside the virtual world. Depending on the scene's purpose, the user position can be set as free or constrained.
  Free: Users may move freely in the scene. It is a good choice for allowing collaborators to access all the locations when necessary.
  Face-to-Face Constraint: Users are positioned face-to-face and constrained. It is a useful property for reviewing objects between two users that don't need to walk through the scene.
  Side-by-Side Constraint: Users are position-constrained beside each other according to the system configuration. It is a valuable technique for gathering a group of users during a mentor presentation task.
  Other: Other characteristics of positioning users and defining their movement constraints. A found research [SMD*19], for instance, presented a mirrored person and workspace to help the communication between users manipulating objects from a scene.
- **Role Symmetry:** This last feature concerns the privileges that users have using the collaborative system. This category was used by [SWB*22] to refer to the role users have. Granting different permissions may help enhance task completion during a collaboration session.
  Symmetric: Users have the same privileges or perform the same tasks.
  Asymmetric: Users have different levels of privileges or assist another user during tasks.

2.2. User Awareness

After describing and classifying the main collaborative situations from immersive environments, we now focus on how users perceive others during collaborative tasks. The possibility of knowing where the users are, where they are looking at, their intentions, and which task they are performing enhances communication and, consequently, collaboration. The crucial design challenges to support collaboration lie in providing sufficient awareness of other users [XHPW18].

Since XR users usually have a lot of freedom in moving and seeing in a 3D space, visual cues play an important role in quickly facilitating the mechanism of making the collaborators aware of others' actions. Thus, with that in mind, we listed and described the primary visual cues used in the proposed user awareness classification.

2.2.1. Visual Awareness Cues

Many studies concerning remote collaboration are dedicated to visual or non-verbal communication cues [KLH*19]. They are intended to enhance and visually extend the collaborator's perception during a task.

Due to technology, it is possible to expand reality and facilitate the awareness that would occur in a natural (real) environment. One example is to be aware of where someone is looking. Usually, a person has to check this by guessing where the collaborator's eyes are pointing. In an XR application, designers can use rays or pointers to aid that information and consequently make this awareness more straightforward.

Above, we describe the following visual cues found in the literature:

- **Rays:** They are visual extensions of a source, like the user's glasses or a controller, intended to reach distant targets. A usual case is mentioned by [TLBA19], which describes a VR controller that points at objects. A virtual ray emerges from the controller, creating a virtual pointer that appears on the surface of an object. Another instance where rays come into play is in navigating a virtual reality environment. Users determine their destinations within the virtual space by aligning their controller's ray in a specific direction and observing its endpoint position.
- **Point of View (PoV):** The point of view cue allows a user to assume another collaborator's perspective without the need to move in the scene physically. This cue is usually generated by aligning one user's head position with another user [PLLB17].
- **Field of View (FoV) Shape:** Its main goal is to demonstrate which region a user is seeing. Through the visual representation of a camera frustum, users can know which region is being seen from other's perspectives. A study [PDE*19] presented an enhanced user performance mixing rays from a head-gaze awareness with FoV Shape from a camera's frustum.
- **Scale:** Scale can be used to change visual dimensions from a scene object and provide awareness to others. A clear example would be when a user needs to review smaller objects with more significant detail. A user's projection size can be used to determine a user's distance from a moderator's point of view, indicating his position [SMF*15].
- **Shadows:** It is a projected shadow from users in a collaborative environment. Scientists [SMF*15] developed representative shadows on a wall display, distinguished by a name and a unique color for each participant. They implemented this cue to depict users and determine their position in a spatial relationship between a person and the interactive surface.
- **Hands:** The visual representation of human hands helps to depict an individual user. Furthermore, hands are essential to facilitate non-verbal communication through natural gestures. Representing hands can be costly, but controllers can visually abstract their position with recent tracking technology. So, this cue is commonly used to point objects during a collaborative task and a visual signal to indicate that a user is manipulating an object [PMR*19].
- **Avatar:** An avatar serves as a visual representation of a system user and can portray real individuals interacting behind a computer or other device. In an immersive environment, it is through this cue, which can vary in appearance, that collaborators become aware of others' presence. The avatars' diverse appearances (i.e., cartoon versus realistic) not only contribute to the visual richness of the collaborative space but may also impact the communication experience [DWG*22].
  Moreover, avatars play a crucial role in fostering social connections among users according to [NB20]. The mentioned research also explored various avatar types (authentic, modified, and non-anthropomorphic representation) correlating them with communication behaviors, such as intimacy and confidence in negotiations.

Table 2: *User awareness and visual cues*

User Awareness		**Visual Cues**	**Papers**
Eye Gaze		Rays	[ELT*19] [PDE*19] [ENK*20]
		Pointer	[PLI*19] [JMLB21]
		Avatar	[RPM*21]
Face Direction		Rays	[PLLB17]
		FOV Shape	[PDE*19] [PLLB17]
		Pointer	[WZB21]
		Orientation	[WKF19]
User Perspective and Frustum		Point of View	[PLLB17]
		Scale	[XHPW18]
		FOV Shape	[PDE*19] [PLI*19]
User Position		Shadows	[SMF*15]
		Orientation	[SMM*17]
User Identification		Avatar	[FKIA20] [DWG*22] [DSM*19] [CDH*19]
		Text	[CDH*19] [KWB23]
Intention	Teleport	Rays	[WKF19]
		Virtual Volume	[XHPW18]
		Ghosting	[XHPW18]
	Iteration Proposal	Ghosting	[PMR*19]
	User-User Interaction	Highlight	[SMM*17]
User-User Relations	Interactions	Highlight	[SMM*17]
	Non-verbal Communication	Facial Expressions	[NB20] [LTC*20]
		Hands	[WWJ*19] [KHJH19] [HKBA19]
User-Object Relations	Selection and Manipulation	Highlight	[XHPW18]
		Hands	[PMR*19] [FKIA20]
	Simultaneous Select and Manipulation	Ghosting	[XHPW18]
	Annotation	Sketching	[KHJH19] [WBB*20a] [HTB*20] [TLBA19]
	Interest Zone	Rays	[CLL*21] [Wol19]
		Hands	[SMD*19]
		Pointer	[KHJH19]
		Symbol	[WZW20]
		Virtual Volume	[ZBZ*23]
User Status		Virtual Volume	[PBHM19]
User Active Tool		Symbol	[WBB20b]
User Roles and Abilities		Symbol	[WF21]
		Avatar	[WZW20] [FKIA20]
User Presence		Avatar	[WWJ*19] [XHPW18] [PLI*19] [RTM*20] [TPP19]
		Shadows	[SMM*17]
		Full-body Avatar	[WWJ*19] [DSM*19] [MSM*21]
User Embodiment		Hands	[WWJ*19] [PLLB17] [PDE*19]
		Full-body Avatar	[WWJ*19] [DSM*19] [MSM*21]
		Controllers	[WF21]

Usually, avatar cues are built using the user's faces. So, to consider the user's full body, we have created a dedicated cue called a full-body avatar.

- **Virtual Volume:** Virtual volumes are volumetric 3D shapes designed to encapsulate a particular subject. Its form may be spherical or cube-like to encapsulate and set a certain property to a selection. For instance, a group of researchers [PBHM19] used a virtual volume to visually indicate a user inside that volume won't hear any conversation outside its zone, creating an isolation mode.
- **Full-body Avatar:** Users can have their whole body represented in an immersive environment using a full-body avatar. This special cue enhances the experience through non-verbal communication, capturing gestures and natural poses. One paper found in the literature [WWJ*19] developed a prototype with full-body avatars to test the communication experience between individuals immersed in the system.
- **Orientation:** Collaborative environments use orientation cues to indicate directions. This cue could be a compass, a map, or anything that guides orientation. For instance, in a collaborative multi-ray jumping task, [WKF19] created a visual compass and a virtual window cue to help passengers be aware of a navigator's viewing direction.
- **Sketching:** Sketching are drawings used to create words, signals, or patterns on the surfaces. Users from a prototype developed by [HTB*20] can easily create sketches on scene objects and leave messages to other collaborators.
- **Facial Expressions:** Facial expressions are a fundamental non-verbal communication type [NB20], which can be seen through avatars or text media when avatars don't support them. It is interesting to mention an uncanny valley side effect of realistic facial expressions, which can predict a negative user experience.
- **Highlight:** It is a color effect feature that indicates attention or focuses on a particular object in the scene. This cue is commonly used in the literature [XHPW18, CLL*21] where the object's wireframe is highlighted with a special color when users select it.
- **Symbol:** Symbol cues are tokens or decorators that designate a message. Weissker and Froehlich [WF21] describe a clear example of a symbol in their research concerning group navigation for guided tours in distributed virtual environments. To help a group follow and quickly recognize which user is the guide, the researchers included a crown (the decorator) on the top of the leader avatar.
- **Controllers:** Most virtual reality systems offer wireless and trackable controllers to interact with objects in a virtual scene. Interestingly, they give a sense of embodiment to users since they are attached to their hands. However, they also help other users to identify which interactions are being performed.
- **Ghosting:** Ghosting denotes a temporary situation that can be turned into a permanent one or may be deleted. This cue changes the opacity of a specific object, presenting the aspect of a ghost. These studies [XHPW18, PMR*19] used ghosting cues to propose new scene versions. Once these versions were approved, the ghosting effect was disabled, or the proposal was deleted.
- **Text:** Texts are important cues to add another layer of information when it is not visually apparent. One example is when developers add names under the avatars to help users identify themselves when only the avatar cue is insufficient.
- **Pointer:** Using a pointer (usually a dot or rounded shape) is a practical way to indicate an interesting zone or even the eyes' direction from other users [KLH*19]. Nevertheless, this is not permanent information, i.e., after pointing to an interesting object, the pointer disappears.

2.2.2. Awareness Types

We present a list of the most frequently found user awareness in the recent literature and connect them with appropriate visual cues. Also, we introduced a Table 2 with the structured information to be used as a reference.

- **Eye-Gaze:** Eye-gaze awareness allows individuals to use natural nonverbal cues to note in which direction other users are looking in real time. Many studies show that eye-gazing improves the interaction between users and their collaborative task performance [NB20]. Pointers, rays, and avatars are the most applied visual cues for users to be aware of the collaborator's eye gaze. One example is a study conducted by [MSKB16], which developed a prototype that shares eye-gazing (through a pointer) with other users using special glasses. According to their user study, gaze sharing improved and promoted the feeling of connection between remote collaborators. Avatars were also used in a study [RPM*21] that augments the real movements with subtle redirected gazes at people.
- **Face Direction:** Following the same principle of natural non-verbal cues from eye gaze, the face direction allows users to identify in which direction a collaborator's head is positioned. Rays, FoV shapes, pointers, and orientation are typical visual cues employed in this face direction awareness. One relevant study [PLI*19] presented CoVAR, a novel MR remote collaboration system using AR and VR technology applying eye-gaze (using rays) and head-gaze (rays mixed with FoV shape) input. They discovered that gaze cues are crucial for improving remote collaboration by reducing task load. Further, a group of researchers [FAMR19] implemented a prototype with a ray emanating from the user's head direction. Interestingly, the ray was also useful for selection purposes. In a teleport task, in which one user brings another one into a collaborative jump, orientation cues are used to avoid motion sickness. The investigators [WKF19] developed a window and a compass (orientation cues) to limit jumping based on the navigator's viewing direction. Pointer cues were used in a study showing that sharing head pointers can improve performance, co-presence awareness, and user collaborative experiences [WZB21].
- **Intention:** Intention is a challenging awareness to track and visually communicate in an immersive environment. Some actions are better understood if collaborators know them before other users execute them. That creates context and common comprehension for all users, avoiding issues like losing orientation and motion sickness. We listed the following intention awareness topics and the appropriate visual cues.

  Teleport: Teleporting is a navigation method in which users change spatial positions, skipping the transition between the start and final destination. It enables users to move long distances virtually when the physical space is smaller than the virtual world.

Rays, virtual volume, and ghosting are visual cues that create awareness of teleport intention. A found study [WKF19] investigated the action of teleporting using rays in a collaborative task. They implemented a prototype that allows users to bring another collaborator to a new position by teleporting together. So, they have created three variations of a multi-ray jumping technique, consisting of a secondary ray for the passive user to be aware of the intention to teleport. Otherwise, they would feel disoriented and suffer from motion sickness. Thus, the teleport intention cues are proposed to warn a user that a collaborator will change position and bring this passive user to a new location in the virtual world. One good example of using ghosting and virtual volumes to indicate an intended teleport task from another user was developed by [XHPW18]. Individuals may create and position another user's avatar with different dimensions to create an awareness of the teleport destination for that user. This special avatar is denoted as a parallel avatar and has a ghosting aspect. In addition, passive travelers get a notification with a virtual volume close to their eyes, indicating the intention of another user to communicate in another location. To teleport, users need to select using a controller on this virtual volume and jump to the final destination.

Iteration Proposal: Scenes may need to be rearranged with new design versions or iterations, including positioning, scaling, and rotating operations. So, aiming at not losing the original state, users can be aware of new designs proposed by other collaborators using ghosting cues. This awareness is developed by [PMR*19] in which it is possible to compare two object versions simultaneously (side by side).

User-User Interaction: Starting communication with other users may not be clear in an immersive environment due to a lack of body representation or facial expressions. Thus, calling the attention of collaborators to start an interaction is the main intention of this user awareness. Highlighting is the usual cue observed in the literature. For instance, [SMM*17] developed a mechanism called bubble maps, which project shapes on the floor indicating an intention to talk. So, these shapes are highlighted based on people's proximity, pointing out the users' interaction intentions.

- **User Identification:** Its main purpose is to help users to identify other users. So, to achieve that, avatars and text are the experienced visual cues more commonly found in the literature. A prototype developed by [ZSM*19] projected an avatar during an interaction so users could recognize who they were talking to with no additional information. Nevertheless, when projecting personalized avatars is not implemented, text cues are helpful to identify users.
- **User Perspective and Frustum:** This awareness concerns knowing what others are looking at during the moment of the interaction. This awareness gives feedback on the direction and the area of another view range, enhancing the context and communication of the target subject. One research [PDE*19] prototyped a visual cue based on FoV shape to indicate the individual's view range and direction. Also, it is possible to see through another collaborator's eyes (using the point of view cue) in a technique called AV-Snap-to-VR created by [PLLB17]. The mirrored user can snap to another user's head with an independent head orientation and minor control of their head position offset to avoid simulation sickness. Other authors [XHPW18] designed another innovative example of user perspective by manipulating the avatar scale. Users may change their size by scaling down their avatars so that others would be aware of these users' perspectives in a scene. Hence, the found cues were the point of view, scale, and FoV shape.
- **User Position:** The awareness of the individual's location in the space during a collaborative experience. Similar to real-world scenarios where a person's position signifies their proximity to collaborators, different communication actions are required based on the distance between individuals. Interacting with closer users is inherently more straightforward than with those farther away. Shadows serve as cues, indicating the distance from a person to a wall and providing a sense of the spatial relationship between them [SMF*15]. Additionally, visual cues such as bubble maps on mobile phones are employed to present user positions within the environment, enhancing awareness of individual locations [SMM*17].
- **User Status:** It indicates and shares the current status of a user with collaborators. The status could indicate different information like the lack of sound (user is not listening) or a concentration requirement (user is focused on a specific task) as demonstrated in a study conducted by [PBHM19]. They have added a virtual volume cue to aid users in being aware of the status of others. So, placing people into a virtual environment shield made them focus on the task without being disturbed.
- **User Active Tool:** It indicates and shares the active tool a user is holding. Before interacting with the scene, a tool icon or a symbol cue can be shown over the user avatar to indicate which active tool users are using [WBB20b].
- **User-User Relations:** The dynamic relation among users is an essential topic in a collaboration environment. Visual cues are key in helping collaborators be aware of others' actions and messages.

Interactions: It is the awareness when users interact with others during a task. Typically, users should be aware if a collaborator is talking or presenting something to others. The typical cues found in the literature are highlights. A prototype [SMM*17] highlights a group when they are closer and start socializing, making other people aware of that social interaction.

Non-verbal Communication: It is nonverbal communication signals that humans use to communicate more naturally. Gestures and facial expressions are typical fundamental components of language that contribute to a spoken message. A relevant paper [MSKB16] investigated a novel technique to explore how effective the empathy glasses were at supporting remote collaboration by using facial expression cues. In addition, hands are familiar cues to express human gestures during a conversation. [HKBA19] presented a study that showed the benefits of using hands for remote guidance with sketching cues for more complex collaborative tasks.

- **User-Object Relations:** These are awareness related to users and the objects in the scene. The lack of context of others' actions during a task tends to generate conflicts of communication or even a lack of resources when users simultaneously try to manipulate the same object.

Select and Manipulation: When users select or manipulate shared objects in a virtual world, collaborators should be aware

of that information, e.g., to avoid editing the same mesh simultaneously when this is not possible. Also, this awareness clarifies which tasks are being executed by individual users.
In the Spacetime prototype [XHPW18], users can reach objects using rays to brush over a set of objects. Once selected, these objects have their wireframe highlighted or collected inside a container, which can be manipulated to move or scale objects.
Another visual cue commonly used is the hands, which can be digitally represented and are crucial to indicate when a user is reaching to grab an object, for example.

Simultaneous Selection and Manipulation: Objects in a virtual environment can be selected and manipulated in some collaborative systems. When these options are available, it is important to warn other users that one collaborator holds a specific object. That avoids unexpected changes in the scene and a lack of context during these tasks.
Ghosting is the visual cue used to generate this awareness. For instance, [XHPW18] denoted a concept called parallel object, in which users can select and manipulate the same object. So, to alert users they have chosen an already taken object, the system changes the object's property, giving an aspect of a ghost.

User Annotation: It is a way of communication among users attached to a scene object. Annotations are crucial in asynchronous collaboration by conveying messages relevant to a specific object. Notably, [WBB*20a] researched sharing virtual non-verbal sketching cues to enhance remote collaboration. They have developed the concept of shared AR Annotations (ARAs), which can enhance co-presence awareness.

Interest Zone: During collaborative tasks, it can be critical to point out an object or an area to create context and make the collaboration task clearer. This is mainly observed in a real-world situation where individuals use hand gestures to point something to another person during a conversation. It is a natural behavior that might also happen in an immersive environment but with more possibilities due to the extension of technology. A good example is the possibility of pointing and seeing occluded objects by creating a transparency area (transparency technique) or by cutting a region away (cutaway technique) using rays and pointers cues [AKK*11]. [CLL*21] studied another use of rays, where they compared the usability of pointing lines versus moving tracks techniques to point out objects before selecting them. Their results showed that pointing lines had a better performance and ease of control over motion tracks. Also, the interest zone identification can be facilitated by adjusting the user's finger direction in a virtual environment [SDM*19]. This technique, called warping deixis, is useful for distant targets in which observers frequently misinterpret the target of a pointing gesture. Virtual volumes were also a visual cue used as spatial area volume [ZBZ*23]. According to the study, they have contributed to a faster task performance time. Finally, a prototype created by [WZW20] allowed users to leave symbols in the form of a flare on the object's surface to indicate an interesting zone to other collaborators.

- **User Roles and Abilities:** In a group session, individuals may have different roles and interaction possibilities. One way to alert users of a role is using symbol cues to identify their roles quickly. A significant example was developed by [WF21], which investigated a group navigation theme from a tour perspective. To help users identify the tour guide among all people, researchers have added a crown symbol cue on top of the guide avatar so other individuals would be aware of that user role. Also, in a paper authored by [WZW20], users' avatars were substituted with virtual reality (VR) glasses to symbolize participants who were engaged in augmented reality (AR) sessions rather than VR. This visual representation effectively conveyed an asymmetrical setup to all collaborators.
- **User Presence:** In synchronous collaboration, when more than one user is engaged, it is essential to make users aware that other collaborators are present at the exact moment. Avatars and full-body avatars are the systems' most common visual cues to indicate users' presence. Also, shadows on a wall can project users on a screen, indicating their presence in a prototype developed by [SMM*17].
- **User Embodiment:** It represents the user's body in a digital space, addressing the user's representation of physicality in remote work [ELT*19]. The represented body parts can enhance natural non-verbal communication (poses and gestures) between users, leveraging collaboration. [WWJ*19] presented one interesting example using full-body avatars (depth-sensor-based) to depict users. With three different avatar control conditions developed (first-person, third-person, and a real-world view), participants indicated better performance in the communication scenario regarding non-verbal behavior cues. Also, hands are a simple cue to denote this particular part of the body, but sometimes, they are not added to the system, which includes a pair of controller cues. Because they are attached to human hands, controllers can represent this body part and be used as a hand in a collaboration task.

3. Discussion

We've classified eight distinct collaborative situations users might encounter when engaging with an immersive application. These scenarios encompass various aspects, from presenting a virtual scene on the screen to users' positioning within the environment. What's intriguing is that these features can also have an impact on users' behavior. Studies have shown correlations between immersion level and computational performance enhancements with users' leadership roles [NB20]. The more immersed they felt, the more talkative they became and the more they were perceived as leaders in the collaborative setting.

It is essential to mention that poor user awareness and cues in collaborative systems can lead to several significant problems like miscommunication, decreased task productivity, reduced coordination, frustration, stress, and reduced engagement among users. This topic deserves further research in assessing the impact of various visual cues on enhancing user awareness in XR scenarios.

Moreover, as immersive technologies continue to evolve, the design and implementation of visual cues must adapt to users' specific needs and preferences. This requires an understanding of the cognitive and perceptual aspects of user awareness and the ability to customize visual cues based on individual and contextual factors. The choice of visual cues should align with the goals of the collaborative environment and the roles of participants, promoting an intuitive and user-friendly experience.

With the advance of new mobile devices and a lack of people's availability to connect simultaneously, it is crucial to study further enhancements in the field of asynchronous collaborative tasks. The exploration of the asynchronous collaboration topic is noticeably smaller than synchronous in the literature [PA20]. However, a large number of synchronous collaboration studies are usually related to exploring the asymmetric setup when users cooperate using different devices at the same time. Notably, there is a lack of studies mixing an asymmetric setup in an asynchronous time.

Another interesting finding is that there are more studies concerning remote collaboration than co-located ones, so investigators focus more on finding solutions to enhance cooperation with distant users.

Regarding workspace awareness, we noted that rays and avatars were the most common visual cues used in many types of user awareness. Interestingly, rays have a common visual style among platforms, while avatars could have lots of variety. Some applications may use custom avatars, authentic, modified, or even realistic full-body avatars, which may impact user experience and task performance. [WWJ*19] describes an example of users rated their non-verbal behavior performance higher in the full-body depth-sensor-based avatar system.

This paper highlights a crucial aspect: the interplay between accurate hand cues and the evolution of tracking technology. Given that humans naturally utilize gestures for communication, hands assume a pivotal role in this dynamic. Fortunately, contemporary systems have advanced to the point of accurately rendering and tracking the positions of hands and fingers. This enhancement provides users with an additional layer of information, enabling the system to discern whether users are pointing to a specific area, engaging in interactive actions, or simply communicating through gestures. Exploring the various options and capabilities these recent technological advancements offer is essential for optimizing the utilization of hand cues.

Due to digital technology, visual cues can expand reality and help users be aware of other users' actions or intentions. There are several opportunities to represent nonverbal behavior in ways that go beyond the limitations of the physical world [MSI21]. For instance, in a real-world case, the intention of going to a specific place in the scene would be confirmed by a user only after the action is finished. Nevertheless, with the aid of visual cues, a ray could previously indicate where collaborators want to go and, at the same time, alert other users of their intention [WKF19]. Using rays for traveling enhances users' awareness, consequently improving collaboration.

Conversely, immersive technology in recent days can also be an obstacle to user awareness. For instance, the size of actual head mount displays makes users' faces challenging to be seen by others. So, to feature facial expressions, developers have to use digital avatar faces to simulate the facial expressions. They can be just a few states being represented unrealistically, or they could leverage an undesired Uncanny Valley effect when presented realistically. Thus, it is key to mention the significant technological challenge and cost of tracking and presenting effective real-time facial expressions in an avatar.

3.1. Open Challenges

Since the immersive collaboration theme is getting traction, we observed the following topics that deserved our attention as open challenges to be further explored.

First, as mentioned in the previous topic, asynchronous collaboration is less explored than synchronous one. Also, there is a lack of studies mixing asynchronous features with an asymmetric setup, which is a field of study to be explored.

One interesting topic to go further is to understand how devices influence collaboration. Smartphones featuring AR have different constraints and interactions than an HMR with controllers in a VR setup. With the emergence of new immersive devices, it is vital to study the relevance of using specific devices and discover if they influence collaboration.

Working in a co-located space in an immersive virtual environment defies collaborators to not collide with each other during a session. Walking needs to be redirected when users are moving around with their HMD. This condition challenges most natural human-human interactions, such as touching another person or walking together through the scene.

Interacting with multi-objects in a collaborative environment is still a challenging topic. A system has to ensure consistent states of the content and overall coherence in case multi-users access the same content simultaneously.

Designing visual cues that can be customized and personalized for individual users and their specific needs remains a challenge. Adapting cues to user preferences and the collaborative context is essential but complex. Furthermore, XR collaborative environments often involve a mix of hardware and software platforms. Ensuring that visual cues work seamlessly across different devices, from VR headsets to AR glasses, is a challenge.

The lack of standardized practices for user awareness and visual cues in XR environments can make it difficult for developers and users to have consistent experiences across different platforms and applications. We noticed different designs for similar cues, like rays or symbols. Standardization is a good practice to enhance user experience.

Creating intuitive and non-intrusive visual cues is essential. Striking the right balance between providing information and avoiding cognitive overload or distractions is an ongoing challenge. Also, XR environments can generate vast amounts of data and visual cues. Managing this influx of information while still preserving user awareness is a complex problem.

Last, this paper's intention category can be explored and expanded to improve collaboration considering the action's intent, like 3D object creation, manipulation, deletion, and design proposal tasks.

4. Conclusion

As a contribution to the field, this paper presented a novel classification of user awareness and related visual cues considering collaborative systems in the XR spectrum. It is intended to be an open guide to help newcomers and experienced investigators quickly access information concerning user awareness and related visual cues.

Thus, we have identified 19 user awareness approaches and 18 visual cues to enhance user communication during specific tasks. Also, we created a classification regarding collaborative situations found on XR collaborative prototypes in the literature. Then, we listed eight unique features with different properties used on XR collaborative systems.

We conclude that user awareness and visual cues play a pivotal role in the realm of collaborative environments, particularly in the context of immersive technologies. These cues connect the physical and digital, offering users a comprehensive understanding of their surroundings, the locations and actions of their fellow collaborators, and the context in which they are operating. Visual cues provide a heightened sense of presence, awareness, and engagement, facilitating more efficient and effective collaboration. They are essential for tasks that demand real-time coordination, communication, and decision-making, and can significantly impact the quality and success of collaborative interactions across various domains.

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