Supporting Artefact Awareness in Partially-Replicated Workspaces

Category: Research

Abstract

Using cross reality approaches for remote collaboration will often result in partially-replicated workspaces. Here, workspace artefacts are not equally accessible—i.e. a physical artefact may only be manipulated by one collaborator—and in general, the artefacts become desynchronised over time. In this paper, we introduce a framework for artefact awareness that can help collaborators maintain an understanding of each others' manipulations with workspace artefacts. We illustrate our design explorations through sketches, and outline how we aim to study the effectiveness and utility of artefact awareness in cross reality remote collaboration. In our work, we expect to show that effectively supporting artefact awareness will help make cross-reality remote collaboration smoother.

Index Terms: Human-centered computing Collaborative and social computing theory, concepts and paradigms—;———H—uman-centered computing Computer supported cooperative work—Human-centered computing Computer supported cooperative work; Human-centered computing Interaction design——

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1 Introduction

Cross reality (CR) offers new opportunities for remote collaboration, and presents new design challenges around awareness. Our interest in CR is focused on how collaborators in different locations will work together in a semi-shared workspace with partial replications of physical objects. As illustrated in Figure 1, such a workspace comprises both physical (in black) and virtual (in blue) objects that are only partially replicated physically: here, object A and A' are paired physical objects in both spaces; object B is a virtual object in both spaces, while object C and C' is a physical object in one space that has a virtual replica in the other space. We envision situations like this will arise in many near future scenarios, including remote assistance/repair, remote teaching/learning, and new forms of physical collaboration.

The partial replication of objects in the two workspaces creates two disfluencies for the collaborators:

1. An interaction problem: *How does a user interact with an object that is virtual as opposed to physical?*
2. An intention/awareness problem: *How does a user communicate with their collaborator about objects?*

For instance, if Alice moves C, presumably this should be reflected with movement of C' in Bob's space. But, if Bob moves the virtual equivalent, C', how should this be reflected in Alice's space? And, should the interaction design be replicated for the other objects, which have different interactional and symmetric affordances?

Our work explores this problem of collaborating with semi-replicated objects, with a particular focus on understanding and designing for what we call "artefact awareness". Artefact awareness conveys the interactional intent of collaborators via artefacts and objects in the workspace. This builds on the rich literature on awareness, which provides us with conceptual frameworks that inform the design of interaction techniques and cues that support effective collaboration at distance [1, 2, 6]. Our work extends this prior work in two ways: First, we consider workspaces that are not flat (cf. [6]), and instead have three-dimensional objects and three-dimensional locations for these objects; Second, our work addresses semi-replicated objects (i.e. objects C/C' in Figure 1).

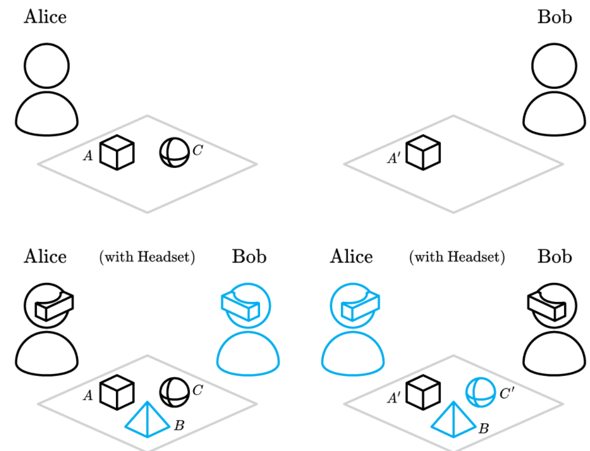

Figure 1: (Top Row) Alice and Bob in separate locations with access to artefacts A, A', and C. (Bottom Row) Remote collaborators interact with physical (in black) and virtual (in blue) artefacts in a shared workspace, featuring avatar representations and replicated artefacts across workspaces ($A \leftrightarrow A'$, $C \leftrightarrow C'$, $B \leftrightarrow B$).

In this paper, we outline the conceptual framework we have built based on our early explorations in this design space. Then, we present early designs for awareness cues, based on artefact awareness concepts. Finally, we outline a study design that aims to understand the differential impact of artefact awareness on remote collaboration activity.

2 Related Work

We briefly outline three areas of related work that set the stage for our work. First, we describe recent efforts to explore CR collaboration, illustrating how their efforts have illustrated instances of partial workspace replication. Second, we discuss how prior CSCW research has described the role of awareness in supporting collaborative work—particularly in the context of remote collaboration. Finally, we outline how the temporal domain is central to collaborative action.

2.1 Partially Replicated Workspaces in Cross Reality

Recent explorations into CR collaboration [9, 20] build on previous research exploring video-based remote collaboration [4, 8, 10, 14–18, 21] in two ways: (1) the notion of workspace extends beyond a flat tabletop/whiteboard to a 3D environment; and (2) one or both collaborators experience the world using immersive AR/VR tools. In recent canonical examples [20], the remote collaborator experiences the local environment in VR through an immersive point-cloud reconstruction that is captured by the local collaborator who looks and moves around the physical space. The remote collaborator's ability to interact with the space is limited to visual annotations, while the local collaborator can grasp, manipulate, and operate objects in the local space. In effect, very little about the workspace is replicated —- simply visual elements are replicated for the remote collaborator. This interactional asymmetry creates communication and efficiency challenges toward task completion.

Yet, partially replicated workspaces will be a common approach for connecting two remote spaces. For instance, [5] explores how to ameliorate disfluencies in how spaces are arranged between two collaborating spaces. In their design explorations, they show how different conceptual connections, different embodiment and visualisation techniques can mitigate some of the challenges presented by two physical workspaces that are not spatially aligned properly.

In our work, we take a slightly different approach, where we are more concerned with the *artefacts* collaborators use and manipulate in the workspace—both physical and virtual. In the tasks we explore, we focus on how they are aligned, and how they move around and operate within the context of a CR collaboration. As illustrated in Figure 1, several new kinds of asymmetries emerge from this arrangement.

2.2 Forms of Awareness in Collaboration

Awareness has been a central concept in CSCW research for many years. In the context of flat workspaces, Gutwin & Greenberg [6] define workspace awareness as an up-to-the-minute understanding of the actions of a remote collaborator's actions and activities in the workspace. Supplying and supporting workspace awareness through visual cues (e.g. [6, 7, 10–12]) reduces the need for explicit communication by supporting consequential communication and deictic references. Gutwin & Greenberg outline several important facets of workspace awareness, including an understanding of other participants' presence, actions, and intentions within the collaborative environment. These include an awareness of remote collaborators' bodies: gaze direction, location and body language.

In our conceptualisation, we view this as a type of "user awareness." In contrast, our focus is on the artefacts in the workspace. Here, Kim et al. [19]'s work is instructive, where they define artefact awareness as "one person's knowledge of the artefacts and tools that other people are working with." In their work, they explain that increased visual detail (on demand) of others' work is useful in supporting transitions to deeper collaborative activity.

This differentiation of artefact awareness from user awareness is important. Our work pushes this definition further, specifically in the context of CR remote collaboration, where we expect partial workspace replication to be commonplace. Based on prior work, we expect artefact awareness to encompass knowledge and understanding of virtual and physical objects and their properties, functionalities, and relationships within a CR space. Effective artefact awareness, like other kinds of awareness for remote collaboration, should improve communication, coordination, and task performance by providing collaborators with a shared understanding of the virtual or physical objects involved.

2.3 Temporal Aspects of Collaboration

Collaboration happens dynamically across various temporal dimensions, significantly shaping the effectiveness of cooperative efforts. By classifying existing work into distinct categories, we understand how real-time, historical, and future-oriented awareness contribute to collaborative work. First, there is the representation of the present [5, 20], which emphasises real-time awareness of events and interactions. Secondly, we have the visualisation of the past, which focuses on capturing and displaying historical movements and actions [13]. Lastly, there is the provision of tools for future-oriented discussions, which involves predictive capabilities to anticipate potential movements and enable collaborators to plan or guide upcoming actions [3].

Using [6] as reference, we noticed that the future was not incorporated due to the expectation of inference, extrapolation, or prediction. We argue that leveraging the suggestive nature of the future provides an opportunity to design an awareness channel that fosters discussions about potential futures and enables a deeper understanding of future collaborative actions. Thus, this invites an another CR collaboration problem: *How should we represent the future/intent of a CR object across semi-replicated workspaces?*

3 A Framework for Artefact Awareness in Partially-Replicated Workspaces

In designing prototypes involving partially-replicated workspaces, it became clear that the differential interactional capabilities of objects created new challenges for collaborators. First, it created situations where physical objects (such as A or A' in Figure 1) might move in one workspace but ultimately not be in consistent locations compared to their physical equivalent in the remote workspace. Second, there may be situations where a collaborator might want to move a virtual object but not be able to (such as C' in Figure 1). Furthermore, it became clear that as part of people's discussion about objects—for example, how they ought to be oriented (i.e. their condition), and where they should go (i.e. their location)—people pick up these objects, and move them around as part of their communicative act. These asymmetries, caused by differential affordances of physical and virtual objects, created communication challenges for collaborators using our prototypes.

We characterise these challenges as arising from a lack of artefact awareness. Artefact awareness focuses specifically on the manipulation, condition, and history of artefacts in the workspace as individual, first-class objects. Table 1 provides a working version of our framework for artefact awareness. This framework borrows heavily from Gutwin & Greenberg's workspace awareness framework [6], though it explores these ideas on a per-object basis.

The framework identifies several needs that emerge from partially replicated workspaces: the idea of intended condition of artefacts (i.e. how a collaborator wants an object to be manipulated), intended location of artefacts (i.e. where a collaborator desires/intends an object to be), as well as communicating historical information about the history of artefacts that may have been temporarily out of view (a common occurrence given the limited field of view of current AR devices).

Visual Interactive Cues for Artefact Awareness. How to realise this framework is a little less clear. In the context of our prototypes, we have designed several small visualisations that realise some of the basic concepts of artefact awareness. Figure 2a illustrates the idea of a "ghost twin", which addresses the problem posed by moving object A or A': when one physical object is moved in one location, how does the second collaborator know that this object has moved? In this case, the ghost twin informs the collaborators about this location asymmetry. Collaborators can choose to relieve this tension by moving their object to match the ghost, or choose to ignore it. Note that the ghost twin can also illustrate certain "condition" differences between the two objects—for instance, that an object may change its orientation somehow. Figure 2b illustrates how this ghost twin illustrates the difference in orientation with an AR arrow that shows the difference in orientation between the two objects. Finally, we observed there are some interactions where the trajectory of an object matters—i.e. that not only does the destination matter, but that the path the object takes may matter. To address this, Figure 2c illustrates the concept of a visual trace of artefacts.

When is Artefact Awareness Useful? Based on our initial explorations, it seems that artefact awareness should support collaborative activity in at least two different ways. First, it enables artefact manipulation for coordination and intent communication: a collaborator can pick up, wiggle, and move an artefact as part of their communicative act. For instance, Alice rather than simply pointing at object C (the "user awareness" approach), Alice can pick up object C, wiggle it around, and say to Bob, "I would like move *this object* over *here*," where she moves the object to a destination location when she says "here." This helps to smooth the communication between Alice and Bob. Second, it allows Bob to communicate intent strictly through the movement of an artefact—Bob can simply move C' as a way

Time	Aspect	Defining Question
Present	Identity	What is the identifier of this artefact?
	Location	Where is this artefact?
	Condition	What is the condition of this artefact?
	Association	What other artefacts are associated with this artefact?
	Emphasis	What artefact is being emphasised?
Past	Location History	What is the past location of this artefact?
	Condition History	What is the past condition of this artefact?
Future	Intended Location	Where should the artefact be?
	Intended Condition	What should the state of the artefact be?

Table 1: Proposed artefact awareness framework, indicating various aspects to consider and categorised by time

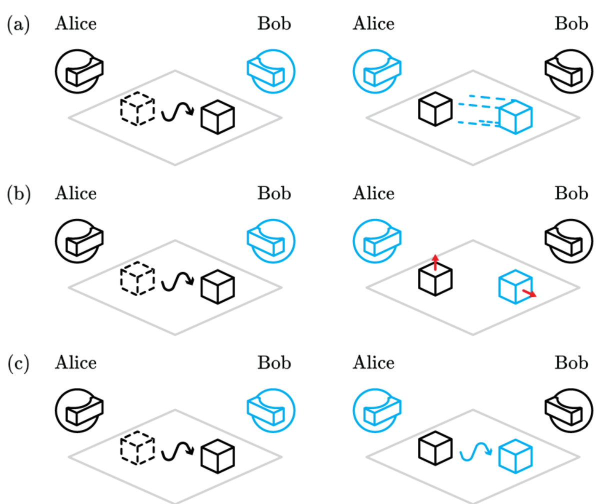

Figure 2: (a) Visual depiction of object movement from the original position to the new position. (b) Indication of orientation change. (c) Visual representation of the path followed by the object from its original position to the new position.

of communicating to Alice of where he believes the object should be. The trace visualisation allows Bob to communicate this to Alice even if she is not watching while Bob makes this move.

One of the interesting ideas that emerges from this work is that it is not always clear which version of the workspace should be considered canonical. For instance, if either (or both!) Alice or Bob moves object A or A', their workspaces will be inconsistent. Our approach here does not signify whose workspace should be considered authoritative; instead, it merely indicates that this particular artefact is inconsistent between the two workspaces. Alice and Bob might want to continue on their train of thought, manipulating objects in ways that make sense to them, without necessarily paying attention to how their collaborative partner is manipulating their objects. Thus, artefact awareness may be something that collaborators want to *turn off* so that they are not distracted. The result of turning it back on would essentially be like a `diff` between the two workspaces.

4 Pilot Study Design

We are interested in exploring the differential impact of user awareness techniques from artefact awareness techniques in remote CR collaboration. As illustrated in Figure 3, users will complete tasks with collaborators with partially replicated workspaces. We realise user awareness through avatar embodiments that are common in today's commercial VR experiences. We will realise artefact awareness as described previously. Participants will complete collaborative tasks that require them to coordinate and communicate about artefacts.

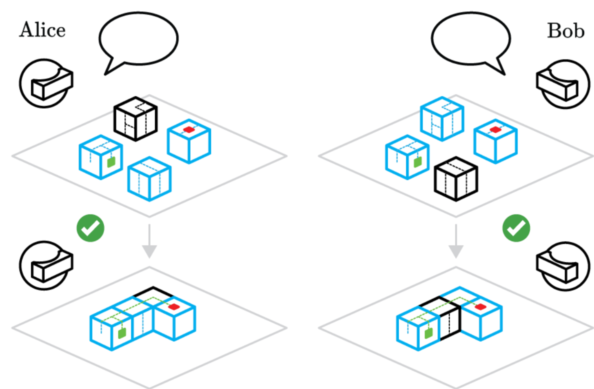

Figure 3: An example of a collaborative task in which each collaborator has access (in black) to only a portion of the shared workspace. In this simplified scenario, the task would be to connect the green and red dots through arranging wires (blocks) into a complete circuit.

Whether awareness cues are effective in collaborative tasks is based on understanding the nature of each specific task. Determining when artefact awareness will be beneficial, and when it may not be pivotal, presents a complex challenge. For example, in a brainstorming session where verbal discussion takes precedence, both User Awareness and Artefact Awareness may not play a central role. However, in tasks that place significant emphasis on the objects involved, such as in an object arrangement task, artefact awareness may be of better use as in Figure 3.

To understand the effects of user and artefact awareness, both in combination and individually, we intend to design a task that enables us to examine these factors thoroughly. With these considerations in mind, we have formulated the following hypotheses for our study:

- **H1** Combining user awareness and artefact awareness will result in improved performance compared to relying solely on user awareness during collaboration.
- **H2** Artefact awareness will benefit collaborators performing certain types of tasks more than others.

By investigating the interplay between user and artefact awareness in collaborative tasks, we aim to gain a better understanding on any advantages and potential synergies between them. Understanding task characteristics will also guide future studies involving artefact-centric tasks, thereby enhancing our overall comprehension of effective CR collaboration.

5 Discussion and Future Work

Within our framework, we expect two central topics to emerge: (1) Design of Artefact Awareness and (2) Task Considerations related to artefact awareness. In exploring Artefact Awareness, we are interested to uncover additional facets beyond those already listed in Table (1). By focusing on specific tasks that stand to benefit significantly from artefact awareness, we aim to distinguish these tasks from others, contributing to a deeper understanding of its potential applications. While our proposed framework provides clear distinctions between each aspect of artefact awareness, we also anticipate that certain design interpretations may lead to overlaps in cues based on their function and purpose. We could inquire on possible CR-related issues such as, ”Who is authorised to interact, either physically or virtually, with the artefact?” or ”Who is currently interacting with the artefact or performing actions on it?”

Effective CR collaboration can be achieved by addressing both the interaction and intention challenges when physical objects cannot be replicated across workspaces. Expanding on our current understanding of artefact awareness, we envision multiple promising directions for future focus:

1. Investigate the optimal combination of artefact awareness cues and the specific types of tasks that would benefit most from such combinations.
2. Examine the impact of artefact awareness on various collaborative configurations, such as Asymmetric Roles and Many ($n > 2$) Collaborators, to gain deeper insights into its effects.
3. Encourage exploration of additional cues beyond the existing artefact awareness framework (Table 1) and identify collaborative tasks that could leverage their use.

Through the comprehensive exploration of the tasks and challenges that emerge under these conditions, we hope our research on artefact awareness will serve as a foundation for creating smooth CR collaborative experiences.

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