Towards a Model for Space and Time in Transitional Collaboration

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ABSTRACT

Transitional collaboration is a unique form of cross-reality collaboration within transitional interfaces. Despite being at different locations of the reality-virtuality continuum, users can closely collaborate and overcome traditional boundaries of space and time. Despite the renewed interest in transitional interfaces as a specific type of hybrid user interfaces, this form of collaboration remains relatively under-explored, primarily since suitable analytical tools and frameworks have been introduced only recently and traditional models from the CSCW community may not fully capture the true nature of transitional collaboration. Therefore, in this position paper, we present the current state of our work on formulating a new model that integrates classic CSCW models with more recent research findings from cross-reality and mixed-reality research on transitional interfaces. We present examples based on existing systems and theoretical literature to demonstrate its practical application, including the visualization of different types of transitional collaboration.

Index Terms: Human-centered computing—Collaborative and social computing—Collaborative and social computing theory, concepts and paradigms—Computer supported cooperative work; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Collaborative interaction; Mixed / augmented reality; Virtual reality

1 INTRODUCTION

Transitional interfaces (TI) are a specific type of hybrid user interfaces that offers users the flexibility to switch seamlessly between various input/output modalities on the reality-virtuality continuum, including traditional 2D screens, augmented reality (AR), and virtual reality (VR) headsets [14]. This capability allows users to select the most suitable visualization and interaction methods for their current task at hand [14], ideally resulting in optimal visual and algorithmic support with maximum cognitive and perceptual suitability [12]. After pioneering work on TIs such as Billinghurst et al.'s MagicBook [1], Grasset et al. introduced a very helpful first conceptual framework to systematically model TIs [5]. It revolves around different *contexts* and the *transitions* between them.

A *context* consists of four components: (1) *space*, i.e., position on the reality-virtuality continuum, (2) *scale*, (3) *representation*, and (4) any other relevant *usage parameters*, e.g., navigation mode. For instance, a context could be a VR environment (*space*) where two users engage inside the simulation of a construction process rendered in photorealistic style (*representation*) at real scale (*scale*) using natural locomotion as navigation mode (*usage parameters*). The *transitions* enable users to switch between contexts at any time. For example, one of the users could transition out of VR by taking off the headset and continue their work on a large touchscreen situated in the real world (*space*) that shows a top-down blueprint of the building (*representation*) in 1 to 50 (*scale*) that can be zoomed and panned using multi-touch gestures (*usage parameters*).

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Collaboration between users and across different contexts has been an integral part of TIs from their very beginnings [1, 5]. However, transitional collaboration is still under-explored and promising analytical tools and frameworks have only been recently published [14]. Moreover, these yet only consider co-located and synchronous transitional collaboration, therefore serving only as an initial step towards understanding the full extent of collaboration possibilities in TIs. In this position paper, we present the current state of our ongoing work on formulating a new model that integrates classic CSCW models with more recent research findings from cross-reality research on TIs. In future work, we plan to verify and further adapt this model, and also show how existing, other frameworks such as coupling styles [8, 15] can be integrated into it. Our goal is to enable a more comprehensive analysis and discussion of the entire breadth of TI collaboration styles and how they can help users to overcome traditional boundaries of space and time.

2 BACKGROUND AND RELATED WORK

Our new model integrates three perspectives and frameworks from well-known CSCW research and own prior work.

First, the very popular Time-Space Matrix, originally proposed by Johansen [6], forms the foundation of our model. It serves as a classification system for collaborative systems by defining the two dimensions (1) Place, and (2) Time, each having the two distinct states same vs. different. By utilizing these dichotomies, collaborative systems can be positioned within this matrix. For instance, e-mail is classified as different place and different time, as it allows communication between users, who are not physically co-located and can respond at different times. On the other hand, a collaborative tabletop touchscreen is classified as same place and same time, as it enables real-time collaboration among co-located users who can interact simultaneously. Therefore, the Time-Space Matrix offers a simplified yet effective approach to categorizing and comparing systems for collaboration. Our model adopts this foundational idea of classifying transitional collaboration based on space and time.

Second, by moving from traditional to transitional collaboration, seemingly simple concepts such as same place become more and more ambiguous. For instance, a VR user could be standing right next to an AR user so that both are physically co-located. However, at the same time, they could be interacting with different virtual objects inside entirely separated virtual workspaces. This situation cannot be simply classified either as same place or different place, since users are simultaneously in the same physical location but might be perceiving entirely different virtual places. In contrast, two users could also closely interact inside a shared virtual workspace as if they were standing next to each other, while being physically separated by hundreds or thousands of miles.

These possibilities go beyond traditional notions of co-located vs. remote collaboration and have led us to reflect about what "space" or "place" actually mean in a TI. In Fröhler et al. [4], we discussed for the first time the need to more precisely differentiate the space dimension in the context of cross-virtuality systems. Additionally, our more recent research discussed new tools for quantitatively analyzing typical distances between collaborators in shared virtual workspaces based on their current context combination [14]. Consequentially, our new model differentiates between two kinds of same place: (1) actual, physical co-location in a shared physical space and (2) virtual, perceived co-location in a shared sensory space.

Third, we conceptualize the dimensions of time, physical space, and sensory space as continua rather than dichotomies. This originates from our prior work about hybrid collaboration [8], in which we show why real-world practices of hybrid collaboration among partially distributed teams elude simple analyses based on the dichotomies of the original Time-Space Matrix. For example, partially distributed teams simultaneously have both co-located and remote members and overcome physical spaces by dynamically creating and adapting shared sensory spaces such as the "group audio territories" we observed in our study [8]. Moreover, such a sensory space can also be understood as a continuum, for example in the case of 3D virtual workspaces in VR/AR as they allow for varying perceived distances between collaborators within the virtual environment [14]. Similarly, also the time dimension can be conceptualized as a continuum between instances of almost zero-latency synchronicity and cases with several minutes to hours between user interactions [8]. We will provide a more comprehensive explanation of this non-trivial relationship in the subsequent sections below.

3 The Transitional Collaboration Model

As discussed before, our Transitional Collaboration Model introduces three continuous dimensions: (1) *physical proximity*, (2) *sensory proximity*, and (3) *temporal proximity*. The physical proximity is determined by the mutual physical or geographic distances between collaborators in the real world. It can range from mere centimeters to thousands of kilometers. In contrast, the sensory proximity is determined by the perceived closeness of collaborators and their feeling of co-presence, even if that closeness is only a technology-mediated illusion and only exists inside a shared networked virtual environment. The third dimension, temporal proximity, determines the temporal closeness of action/reaction or cause/effect events during collaboration. It begins with barely noticeable technical latencies in the range of milliseconds to clearly perceptible time differences of seconds, minutes, or circadian rhythms, e.g., days or weeks. Furthermore, all three dimensions are now conceptualized as continua rather than dichotomies ranging from the least to the most tightly coupled collaboration. By this, it enables a more detailed analysis and improved differentiation of the much greater variety of specific collaborative situations in TIs compared to traditional CSCW tools. The following section illustrates each dimension with relevant examples.

3.1 Physical Proximity

The *physical proximity*, (see Fig. 1), characterizes collaboration based on whether or not individuals share the same physical environments. The continuum ranges from *fully engaged*, where collaborators share the same physical space to *fully disengaged*, where they are physically distant from another. Between these endpoints lies partially engaged collaboration, where participants are neither fully engaged nor fully disengaged.

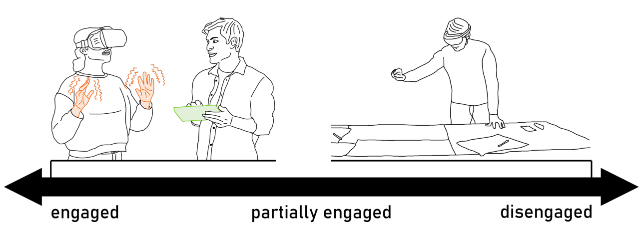

Figure 1: The physical proximity dimension.

Fully Engaged During full engagement (see Fig. 1, left), collaborators share the same physical space. For example, two users in VR sharing one tracking space or a person in reality approaching a collaborator in VR to hand them a physical object like a tablet. From these examples we already see, that (1) especially immersed users must be cautious to avoid collisions with others (see Fig. 1, orange), and (2) it becomes effortless to interact with each other like naturally passing objects to fellow collaborators (see Fig. 1, green).

Regarding the avoidance of collisions between immersed users and bystanders, Kudo et al. investigated how bystander awareness and immersion in VR systems can be balanced [7]. Despite the risk of collisions, immersed and non-immersed users can also profit from physical co-location and their inherit possibility to interact with each other. O'Hagan et al. conducted a review of such interaction forms between co-located VR users and non immersed bystanders within 14 different systems [9].

Fully Disengaged In fully disengaged situations, collaborators operate remotely and have to rely on computer-mediated collaboration. A hypothetical scenario involves a collaborator working at a desktop PC in their office, while their partner manipulates 3D objects in VR using specialized tracking technology in a designated room within another building (see Fig. 1, right). In contrast to the above mentioned fully engaged scenarios, immersed users have ample space for spatial interaction forms, such as exploring expansive spatial datasets. However, the transfer of objects such as work results can only take place virtually.

Partially Engaged The intermediary positions along this continuum encompass partially engaged scenarios. These scenarios may arise due to hybrid collaboration, wherein teams consist of of both co-located and remote members [8], or situations where collaborators are spatially-confined to distinct areas within the same room or to different rooms but remain in walking distance. In such instances, the spatial separation makes collisions between users but also physical object exchanges impossible. Nevertheless, collaborators remain close enough to walk to each other without much effort to facilitate interactions, such as exchanging objects, if necessary.

3.2 Sensory Proximity

In contrast to physical proximity, which can be objectively measured in the real world, *sensory proximity* is intended to capture the subjective distances perceived by collaborators and ranges between *fully engaged* to *fully disengaged* (see Fig. 2). A higher level of engagement can be achieved with a greater number of mutually perceived elements, which include, but are not limited to (1) shared audio spaces (see Fig. 2, orange), (2) representations of fellow collaborators (see Fig. 2, blue), and (3) individual data elements within the dataset and their current representation (see Fig. 2, green). Furthermore, a higher engagement can also be achieved when users stand in close proximity to each other within a virtual workspace with a realistic, fully articulated representation of their collaborators.

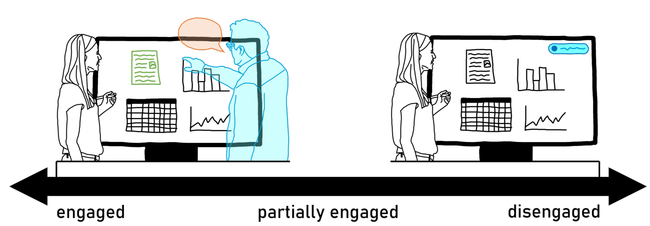

Figure 2: The sensory proximity dimension.

Fully Engaged Full engagement can naturally occur e.g. if two users stand together in front of a large collaborative display in reality. However, it can also be computer-mediated when two users collaborate remotely, perceiving each other through a constantly shared audio space and fully articulated avatars, while discussing exactly the same documents within their workspace (see Fig. 2, left). Examples of fully articulated avatars have been extensively researched in terms of their design [10] and their impact in collaborative scenarios in AR [16].

Fully Disengaged In contrast, in fully disengaged situations, collaborators are operating in perceptually separated spaces within the workspace. They either perceive different parts of the workspace or utilize alternative representations of the workspace. For example, an aerodynamics expert and a design engineer collaborate in a laboratory through a shared virtual workspace on the aerodynamic design of a vehicle component. The aerodynamics expert is working at a desktop PC situated in the real-world lab and alters parameters of the airflow simulation, while the design engineer, immersed in VR, redesigns the relevant vehicle component based on new requirements. Their collaboration does not require them to see each other as avatars; a simple awareness cue informing them about the presence and identity of their partner is fully sufficient (see Fig. 2, right). Moreover, they focus on different objects within the workspace: the aerodynamics expert on the simulation parameters and the design engineer on the vehicle component. While the former interacts with a 2D interface, the latter works inside an immersive 3D environment. They do not share the same representation of their partner, nor do they share objects in the workspace or necessarily have a shared audio space. Thus, while focused on their respective tasks, they are completely disengaged from each other.

Partially Engaged However, most collaborative scenarios are likely to fall between these endpoints, where only selective elements of the workspace are mutually perceived. An example of partial engagement is when the aerodynamics expert and design engineer need to discuss a specific detail of vehicle component from their respective workstations. Both then communicate about the same object of the workspace in a shared audio space, but they would still lack a visual representation of each other and continue to have different representations of the component itself (2D vs. 3D).

The transition from more engaged to more disengaged scenarios has also been frequently observed in current research. For instance, in the domain of hybrid collaboration, we discovered that teams created "group audio territories", with individual collaborators frequently alternating between shared and separate audio spaces [8]. In the area of transitional collaboration, our recent study revealed that specific context combinations can afford preferences for specific virtual distances between collaborators [14]. Additionally, research on user representations in the form of avatars in mixed reality (MR) has been conducted, exploring how avatar design can be adaptive to specific contexts [11].

3.3 Temporal Proximity

Temporal proximity (see Fig. 3) describes the degree of synchronicity in events and action sequences between collaborators. This synchronicity is influenced by three factors. Firstly, technical latencies can force collaboration to become asynchronous. These latencies are closely related to physical proximity, as at least one millisecond of latency occurs for every 300 kilometers due to the speed of light. Secondly, collaborators in different time zones may have varying daily rhythms, making synchronous collaboration impractical. Thirdly, collaborators may deliberately choose to decouple themselves from surrounding events and focus on their own task, catching up with surrounding events at a more convenient time.

We define a continuum from *fully asynchronous* to *fully synchronous* collaboration. To enhance the quantification of how such latencies affect transitional collaboration, we integrated a neurological model of time perception and timed behavior, which classifies time periods into milliseconds, seconds-to-minutes, and circadian rhythms [2]. Consequently, we categorize transitional collaboration as (1) synchronous with latencies in the millisecond to zero range, (2) partially synchronous with latencies ranging from seconds to minutes, and (3) asynchronous with latencies exceeding that timescale. These temporal intervals are processed independently in different brain regions and play a crucial role for different activities (e.g., millisecond perception is essential for speaking [2]). This neurological model enables us to analyze whether collaborative tasks and actions become unfeasible due to the lack of synchronicity. The following subsections will elaborate each category, including concrete examples.

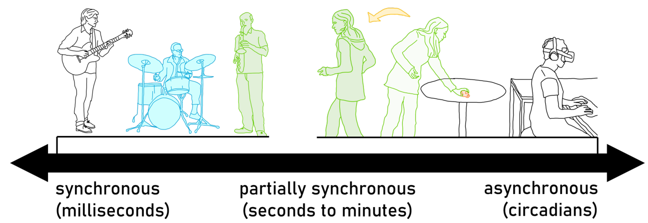

Figure 3: The temporal proximity dimension.

Fully Synchronous Fully synchronous collaboration is the most extensively researched collaboration in MR studies so far [4]. In this type of collaboration, users deliberately work together within milliseconds to zero latency to ensure instantaneous interactions. Neurologically, millisecond time intervals are critical for precise movement control and auditory processes such as speech [2].

Schlagowski et al. explored the feasibility of remote jam sessions in MR, illustrated in Figure 3 (left) [13]. While collaborative music-making is an intentionally synchronous activity, technical limitations introduce latencies between individual participants. Up to 43 ms is considered as an acceptable latency for music-making, therefore jam session participants cannot be separated by more than about 13,000 km due to the limitations of the speed of light. Beyond this distance, collaborative music-making becomes unfeasible due to latency issues [13].

Fully Asynchronous As discussed at the beginning of this subsection, we consider collaboration between users to be fully asynchronous if either (1) technical latencies are within circadian rhythms (e.g., space missions), (2) collaborators have different work rhythms (e.g., living in different time zones), or (3) collaborators deliberately choose to work independently and catch up with surrounding events later (e.g., answering emails).

An example of a system that allows asynchronous interaction between VR users and their non-immersed collaborators is AsyncReality, shown in Figure 3 (right) [3]. In this system, VR users can activate a focus mode when they need to concentrate on a particular task. During this mode, the user is visually and acoustically isolated from their environment, allowing them to focus all their senses on the task at hand. External collaborators who are not immersed in VR cannot interact directly with the VR user since the user cannot perceive them. However, these external collaborators can leave physical objects and voice messages for the VR user in focus mode. The system records such events and generates a causality graph, capturing the causal relationships between the happened interdependent events during focus mode. This allows the VR user to replay these events in a causally consistent manner at a more convenient time. This qualifies AsyncReality as an asynchronous collaboration system.

Partially Synchronous Situations between the two endpoints above are classified as partially synchronous. An example of partial synchronicity would be to allow VR users to set preferences within the AsyncReality system that would allow certain non-immersed collaborators to interrupt the VR user in focus mode while others could not. The VR user therefore would stay synced with some collaborators while still beeing completely async with the others. In terms of latency, such situations would be in the range of seconds to minutes. In this case, fine motor tasks become challenging, but planning behavior would still be feasible within this time interval [2].

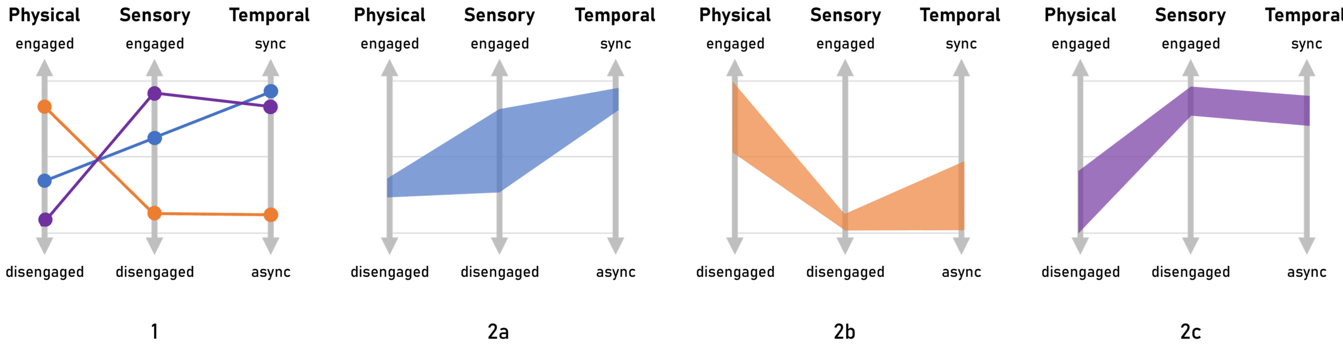

Figure 4: Visualization of (1) specific collaboration scenarios, and (2) multiple aggregated scenarios from three MR collaboration systems. Blue: designing the illumination of a fictitious urban park [14]; Orange: AsyncReality [3]; Violet: collaborative music-making [13].

4 Application of our Model

In the following section, we present a first attempt at applying our new model by analyzing collaboration scenarios from three exemplary systems. We will also use parallel coordinates as a first step to visualize two levels of collaboration data: First, individual situations plotted as a discrete line along the dimensions (see Fig. 4-1), and second, aggregated data encompassing multiple collaboration scenarios by plotting an area along multiple points on the dimensions (see Fig. 4-2). The latter could include, for example, all situations provided by the system or all potential situations that would unfold within a given context combination. All three examples are color coded in Figure 4.

Example 1: Collaborative Park Lighting Design As part of our recent study on transitional collaboration, we created a prototype in which participants had to collaboratively design the illumination for a fictitious urban park [14]. Within this prototype, users could freely switch between three contexts: (1) a 2D desktop PC, (2) tablet-based AR, and (3) VR through a head-mounted display. We artificially distributed functionalities and visualizations so that participants had to switch between and collaborate across different contexts. In addition, we restricted each participant to their own physically separated workspace with their own devices. Thus, users could not share the same device or use their collaborator's device.

The scenario chosen for further analysis involves a participant sitting at a desktop PC analyzing the quality of the illumination design they have created. Their partner is immersed in a VR environment, adjusting and evaluating the intensity of individual lamps in the park. Although they were in the same room, they were physically confined to their respective workspaces. Therefore, in terms of physical proximity, the participants were partially disengaged. However, in terms of sensory proximity, they were discussing the same lamps but using different visual representations of the data. They shared an audio space and had a visual representation of their collaborator. Therefore, they were close to fully engaged. In terms of temporal proximity, their collaboration was fully synchronous, as they were actively engaged in discussion. In addition, technical latencies were negligible because they were in the same lab. The visualization of this scenario can be seen as the blue line in Figure 4-1.

When examining all collaboration scenarios afforded by this context combination (PC-VR), the primary source of variation was observed in the sensory proximity between the two participants. While their audio space was always shared, they did not always shared the same visual perspective or were in different locations within the virtual workspace. As a result, their sensory proximity shifted between more engaged and more disengaged situations based on their respective foci. Therefore, the aggregated area shown in Figure 4-2a is wide along the dimension of sensory proximity, but very narrow along the other two dimensions.

Example 2: AsyncReality The second scenario comes from the AsyncReality system. As previously described in Section 3.2, an object can be placed on the desk of a VR user in focus mode [3]. During this moment of physical proximity, both users are considered fully engaged. However, because the VR user is focused on a task within the VR environment, detached from their surroundings, they are fully disengaged in terms of sensory proximity and fully asynchronous, which is visualized by the orange line in Figure 4-1.

If we imagine an office with this system, we can conclude that users are constantly in a range of partial to full engagement in terms of physical proximity because they are in the same office and can approach each other when needed. In terms of sensory proximity, collaborators are primarily fully disengaged, as the VR user is working in a focused cognitive state that disconnects them from their surroundings. In terms of temporal proximity, this example is primarily asynchronous. However, if the system were to allow certain collaborators to interrupt the VR user's focused mode, this would expand the range on this dimension to partially synchronous. These aggregated scenarios are visualized in Figure 4-2b.

Example 3: Collaborative Music-Making The last example illustrates the system for collaborative music-making in MR as presented in Section 3.2 [13]. The collaborators are physically distant from each other, resulting in a fully disengaged physical proximity. Despite the physical distance, the collaborators engage in music-making together while visually observing and reacting to each other's improvisations, leading to a fully engaged sensory proximity. In addition, the collaborators are fully synchronized despite the higher latency caused by the physical distance. This scenario is illustrated by the violet line in Figure 4-1.

Physically, users within this system are generally at least partially disengaged (e.g. in different apartments within the same building), but primarily fully disengaged. This can be seen in Figure 4-2c which shows all potential collaboration situations. However, collaborative music-making leads to high sensory engagement. Furthermore, they are synchronized as best as possible, given the inherent technical latency.

5 Conclusion

This position paper presented the current state of our work towards the creation of a generalized Transitional Collaboration Model. This model is intended to enable researchers to analyze and compare the complex nature and unique aspects of transitional collaboration. We already based our model on well-established, popular frameworks and recent findings from the CSCW community, supplementing it with relevant practical examples. Additionally, we also presented possible applications and initial visualizations of our model. We consider this preliminary model to be a good first step for our future work in analyzing and generalizing transitional collaboration.

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