Utilizing F-Formations in Collaborative Cross-Virtuality Analytics Scenarios

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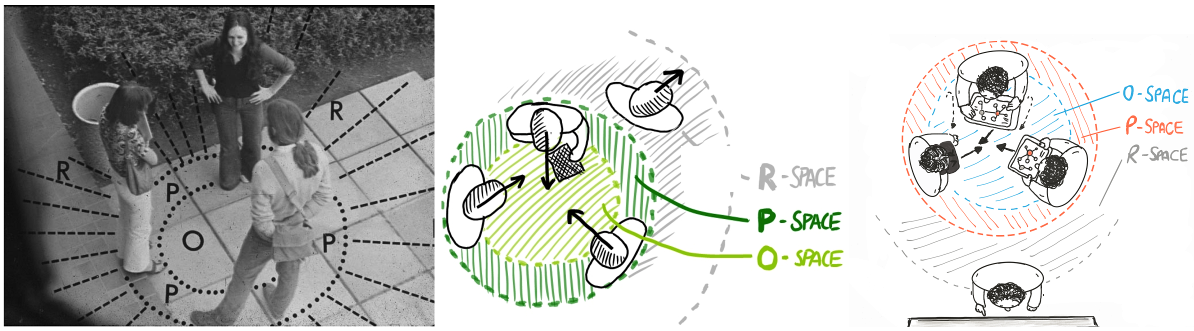

Fig. 1. Evolutionary use of f-formations. From the real environment (left [8]) over cross-device interaction (middle [14]) to its application across entities at different stages of the reality-virtuality continuum (right).

In this position paper we present how the sociological concept of f-formations describing informal, social encounters can be utilized to create novel ways of interaction along Milgram's reality-virtuality continuum in co-located, collaborative scenarios. After outlining the fundamental principles of f-formations and its current applications mainly in cross-device interaction, we describe how this concept can be applied to cross-virtuality interactions by discussing an exemplary use case for cross-virtuality analytics. We conclude by assessing the potential use of f-formations for cross-virtuality interaction if this concept is applied not only to the real environment, but also extended to entities at other locations of the reality-virtuality continuum.

CCS Concepts: • **Human-centered computing** → **Mixed / augmented reality**; **Virtual reality**; *Computer supported cooperative work*.

Additional Key Words and Phrases: cross-virtuality interaction, mixed reality, f-formations, cross-virtuality collaboration

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1 INTRODUCTION

Cross-virtuality analytics in our understanding tries to maximize use of immersive analytics [2] to its full extent by interconnecting conventional 2D interfaces in the real world with virtual environments across the entire spectrum of the reality-virtuality (RV) continuum, ranging from the real environment over augmented reality

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(AR) to virtual reality (VR) [15]. By seamlessly integrating and transitioning entities along this continuum, users can be provided with adequate visual and algorithmic support that adapts to the current context of analytics tasks [22]. The support of devices at different stages of the RV continuum in this context [7] allows the combination of their respective advantages, such as multi-touch input, passive haptic feedback and physical navigation in front of large 2D displays [9], the stereoscopic capabilities and unlimited workspace [17] of modern head-mounted displays (HMDs), as well as the high degree of immersion and adequate use of 3D data visualization in VR [10]. Novel HMDs such as the Varjo-XR3[1] enable with their high-resolution cameras also the transition from VR via video-based AR to the real environment and vice-versa without having to remove the HMD.

We aim to exploit these benefits to support the rather complex exploratory analysis of network data represented as graph networks. This is achieved by moving and transforming 2D graphs on a multi-touch-enabled large-scale display into a 3D target layout in AR 3D space by performing a pull gesture, so that the benefits of 2D and 3D data visualization can be combined [23]. While this approach enables the transition of data visualizations along the RV continuum, its support for interconnecting users at different stages of the continuum is rather limited, although such complex tasks are frequently tackled collaboratively [26]. Whereas a large-scale display could be used as shared workspace, users without an HMD require also a personal workspace such as mobile devices, as coupling styles between loose and tight collaboration switch frequently when working on complex tasks as a team [16]. Common awareness cues such as head pose, eye gaze and embodiment can help to improve collaboration with HMD users [21], in particular if the HMD-wearing user decides to transition to VR, but offer per se no facility to easily share content and findings between users in the real environment and the HMD user.

We believe that f-formations [8] - a well-established concept from social sciences describing informal, physical encounters - can close this gap by forming the basis for novel seamless and fluent interactions between co-located users at different stages of the RV continuum.

2 F-FORMATION FUNDAMENTALS

F-formations originate from social sciences and describe distinctive spatial arrangements of people during physical encounters that involve group discussions [4, 8]. Its key components are formed by three different spaces (see sample f-formations in Figure 1):

- **O-Space:** The o-space forms the center of the formation and is isolated from the environment by the participating entities. It is used as shared collaboration space that can also contain physical artefacts like documents or mobile devices.
- **P-Space:** The p-space represents the boundary of the f-formation and is defined by the roughly circular area in which the participants of the interaction arrange their bodies during the encounter [8]. This space is also used as a retreat area for body parts or artefacts that a member of the formation wants to move out of the o-space, for instance after finishing to show the other group members content on a mobile device [14].
- **R-Space:** The r-space represents the area beyond p-space and defines the environment of the formation. Entities in r-space are not participating in the formation.

F-formations are not a rigid structure, they can change shapes and size depending on the type of task and participants can perform transitions in the f-formation, for instance leaving the formation into the surrounding r-space or turning away from other participants [8]. There is no maximum number of members in an f-formation, but they rarely exceed a diameter of 1.7 meters as this perceived as maximum distance for comfortable face-to-face conversation and 95% of freely forming groups do not exceed four persons [6]. The idea of f-formations is also not limited to human beings, other entities such as large-scale displays can become part of a formation if users gather around it to view shared information [14]. Other fixed features such as furniture in a seated environment still allow the creation of f-formations, but discourage dynamic adaptions during its life-cycle [4].

[1] https://varjo.com/products/xr-3/

3 CURRENT APPLICATION AREAS

Apart from its origin in social sciences, f-formations have been discussed in image processing [25], in robotics to sense presence of human users [11, 12] and for use in cross-device interaction [14, 24]. For instance, the *GroupTogether* prototype detects f-formations in a collaborative setting with overhead Kinect cameras mounted on the ceiling [14]. With tracking data from radio modules attached to mobile devices, a mapping which device is used by which person in the f-formation is established. Based on these relationships, several spatially-aware [1] cross-device interactions for moving and duplicating content across devices are evaluated, such as flipping and tilting gestures between different mobile devices or mobile devices and a large-scale 2D display.

In VR, trials have been conducted to extend the field-of-view of f-formations by equipping a VR HMD with a 360° camera and multiple external displays, so that VR users and users in the real environment can perceive a social encountering as f-formation, although they do not face each other [5]. Other related work determines how the degree of involvement of VR users in a multi-user encountering can be influenced by virtual agents that share their virtual f-formation [20]. There have also been trials how f-formations with and without shared objects between co-located VR users can influence task performance in a collaborative learning task [3].

First research initiatives have f-formations already analyzed in cross-virtuality scenarios to evaluate collaboration styles between users in the real environment using a mobile device with users in VR using an HMD [19], but do not focus on co-located design decisions, as f-formation detection is bound to the virtual camera of the mobile device user, which can be moved around freely by touch input in the shared virtual environment.

4 F-FORMATIONS IN COLLABORATIVE CROSS-VIRTUALITY ANALYTICS

F-formations have already been successfully deployed in collaborative scenarios in the real environment to overcome frequently as awkward and clumsy perceived manipulation, sharing and information display facilities on and across multiple devices [14]. However, their potential use in co-located, cross-virtuality collaboration remains largely unexplored. We believe that maintaining knowledge about participants, state and shape of f-formations during collaboration provides a powerful tool to design spatially-aware cross-virtuality interactions that better interconnect users in the real environment with users in AR and VR in particular. Not only can the system utilize knowledge about f-formations to enable new ways of interaction, but also awareness between users at different stages of the RV continuum can be improved.

The required proxemic information to base interactions on f-formations can be derived by tracking users along the RV continuum similarly as in the *GroupTogether* prototype [14] or by deriving their current f-formation state to some extent indirectly from the tracked devices they are using (i.e. head-tracking-enabled HMDs and mobile devices equipped with trackers). In our scenario of co-located, collaborative cross-virtuality analytics of graph networks we expect that team members frequently switch between phases of loose collaboration in their personal workspace and tight collaboration in which they gather in f-formations to share new observations and findings.

If users in the real environment approach HMD users immersed in VR to share new findings, an avatar of those users can be displayed in VR so that shape, participants and tracked artefacts in o-space of the created f-formation are accessible at both stages of the RV continuum. This approach would allow utilizing the unlimited workspace in VR for visualizations that due to their scale, navigation and manipulation facilities cannot be augmented in the real environment, but might be required in the current context [13], while still not isolating VR users fully from the physical environment. If the current task requires a more natural conversation between users in VR and users in the real environment, HMD users can also switch from VR to video-based AR if supported by the device to continue their analysis in AR and to see the real users instead of their virtual representations in the f-formation.

The use of f-formations as a basis for cross-reality interactions is however not limited to specific HMD display technologies. For instance, in a face-to-face formation, new methods for content transfer between users with non-XR devices in the real environment and both, VR and (optical) AR HMD users and can be enabled. We can for

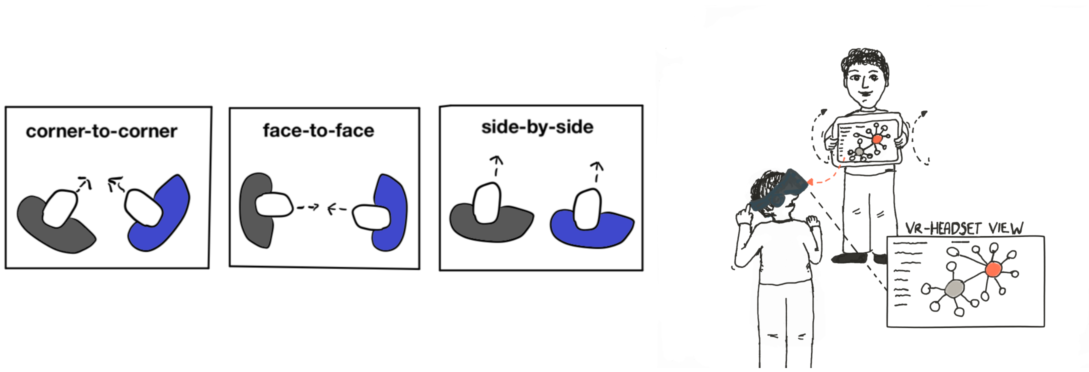

Fig. 2. Left: different common shapes of f-formations on which spatially-aware cross-virtuality interactions can be based. Right: exemplary cross-virtuality interaction in which mobile device content can be shared with users in AR/VR by tilting the mobile device towards the other user if they currently participate in an f-formation.

instance think of a tilting gesture with which tablet users in the real environment can share their 2D visualization currently displayed on the mobile device screen by tilting the display towards the HMD user if they are facing each other in an f-formation (sketch in Figure 2). This enables users to work with visualizations that are more suitable for 2D such as adjacency matrices [18] on mobile devices and to share them with HMD users being immersed in 3D visualizations if required.

During its life-cycle, the shape of the f-formation can also change depending on the current context of the task (see sample shapes in Figure 2). These cues can for instance be used to highlight areas of common interest in visualizations that are shared in o-space if a corner-to-corner shape is currently used.

5 CONCLUSION AND FUTURE WORK

We believe that f-formations can provide a rich toolset for co-located cross-virtuality collaboration to create novel ways of interaction between users in the real environment and users being immersed in augmented or virtual reality. They can complement common awareness cues by interweaving users on different stages of the RV continuum in a way that allows a fluent exchange of content and findings, which appears vital to us in a collaborative data analysis task. To draw qualified conclusions about the usefulness of f-formations in co-located cross-virtuality collaboration, we recommend to conduct a qualitative user study with a demonstrator application to see how participants actually use these new forms of interaction.

We also envision the development of an open-source framework that provides an API for the observation of f-formations between HMDs, tracked devices in the real environment and static entities such as large-scale displays with off-the-shelf hardware such as arbitrary HMDs with head tracking and Vive trackers. By providing events not only for the detected formation, but also for transitions of entities between o-, p- and r-space in the formation and changes in the formation's physical arrangement we assume that a wide variety of cross-virtuality interactions is possible and we would be curious what the research community can achieve with it.

In this workshop, we would like to discuss our current findings what appropriate interaction paradigms utilizing f-formations might look like in co-located, collaborative cross-virtuality interaction.

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