Tent Mode Interactions: Exploring Collocated Multi-User Interaction on a Foldable Device

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ABSTRACT

Foldable handheld displays have the potential to offer a rich interaction space, particularly as they fold into a convex form factor, for collocated multi-user interactions. In this paper, we explore *Tent mode*, a convex configuration of a foldable device partitioned into a primary and a secondary display, as well as a tertiary, Edge display that sits at the intersection of the two. We specifically explore the design space for a wide range of scenarios, such as co-browsing a gallery or co-planning a trip. Through a first collection of interviews, end-users identified a suite of apps that could leverage Tent mode for multi-user interactions. Based on these results we propose an interaction design space that builds on unique Tent mode properties, such as folding, flattening or tilting the device, and the interplay between the three sub-displays. We examine how end-users exploit this rich interaction space when presented with a set of collaborative tasks through a user study, and elicit potential interaction techniques. We implemented these interaction techniques and report on the preliminary user feedback we collected. Finally, we discuss the design implications for collocated interaction in Tent mode configurations.

CCS CONCEPTS

• **Human-centered computing** → **Interaction techniques**; **Interaction design**.

KEYWORDS

foldable display; tent mode; gesture input; physical device manipulations; multi-user interactions

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1 INTRODUCTION

The emergence of flexible materials and smart mechatronics has led to a novel class of deformable electronics [61] and foldable displays [52]. The conventional smartphone and tablet, designed as a rigid, single-sided display is evolving into a foldable device as seen with the consumer ready Galaxy Fold [51], the MateX [17] or the Microsoft Surface Duo [35]. As envisioned by HCI researchers as far back as a decade ago [14], such foldable devices possess significant untapped potential for numerous innovative interactions [9, 24, 27, 28, 50, 59].

In particular, mobile devices that fold into two or more sub-displays provide an additional means to those currently used, for collocated work over just a single device [14]. Handheld devices are designed for personal use, but are sometimes used for sharing content among collocated users. However, prior art notes that even briefly lending one's phone raises privacy concerns [23] and is intrusive [12]. Cross-device interactions also enable collaborative work [13, 31, 32], but require constant connectivity between devices [13] and increased mental demand [43]. Ad-hoc collaboration by using each user's individual device (without cross-device interaction) is also common, but needs to be enhanced with verbal or visual feedback [2] for users to coordinate effort. Collaboration on a single handheld device is also common, and often requires the owner to re-adjust the device angle or their f-formation (i.e. how they are positioned relative to one another). Sharing one device mitigates

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problems such as trust and coordination [14], but more importantly, lacks in providing a simultaneous shared and personal space for sensemaking collaboration [16]. Such division of display resources has been shown to facilitate fluid content sharing in multi-user settings [58], as demonstrated with larger tabletop [19, 37] and wall displays [30]. It is unclear how such distribution of display space facilitates content sharing and group effort on a foldable, personal device.

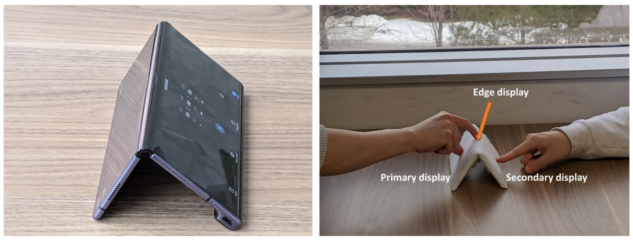

Figure 1: (Left) A consumer-ready foldable mobile device, the Mate X. When folded, or in Tent Mode, (Right) the device facilitates face-to-face collaboration through the availability of a Secondary display, as well as a shared Edge display as shown on our foam-board prototype.

Researchers have hinted at the value of using foldable handhelds for ad-hoc collaboration when the device is folded into a convex battleship [14] or bridge [32] configuration. However, these early works have not provided specific interaction guidelines that are tailored to the unique form factor the device takes. In this paper, we extend these earlier proposals by seeking to answer whether such a form factor can facilitate content sharing - while having the nature of a personal handheld device - and if so, what are the mechanisms to support it. In such a setup, the two major displays of the device are slanted and assume the shape of a ***Tent*** (Figure 1). Rather than using distinct displays as in battleship or bridge, in our *Tent mode* design exploration, we partition the single display of a foldable device into three sub-displays, two outward facing and one on top, between the two (Figure 1) which throughout the paper is referred to as the **Edge** display. This opens an opportunity to explore how such partitioning of display space including a shared Edge display facilitates the nuances of both individual and collaborative effort on a single device while mitigating the aforementioned issues such as cross-device overhead and single-device privacy. As an illustrative example, imagine a scenario wherein the owner of a foldable device strikes a conversation with a stranger sitting across on a train. The owner wishes to show the stranger some photos, but without a) moving across to sit side-by-side, or b) handing over the device to preserve privacy from incoming messages or other apps. As such, the owner quickly folds the device into Tent mode, with the primary display facing herself, and sends select photos to the Edge display. The stranger selectively picks photos from the Edge onto the secondary display and continues conversing with the owner, all without disrupting the owner's privacy, their seating positions, or their flow. Our search for novel Tent mode interaction methods is motivated by the above, as well as the many ad-hoc content sharing scenarios.

The objective of the studies addressed in this paper is to explore the design space for collocated ad-hoc multi-user interactions on Tent mode and to propose interactions techniques brought prominent by this form factor. Through a systematic exploration, we first assess whether end-users identify conventional mobile apps to be suited for collocated collaboration in Tent mode. We find that users clearly envision a collection of apps (including browsing Photos, Youtube and Maps) suitable for multi-user interaction in Tent mode, irrespective of how each user faces one another. We further propose a range of Tent mode interactions based on the degree of display real-estate needed or physical manipulation of the device and elicit from users how these can be employed in the context of user-identified popular apps. We find that users associate many of the collaborative tasks with operations unique to Tent mode interactions, such as heavily relying on a 3rd, shared sub-display (Edge display, Figure 1) for placing content or for giving users awareness of each other's activities. We implement the suggested Tent mode interactions and through an informal observation confirm the benefits of Tent mode operations for collocated multi-user scenarios.

Our contributions toward foldable mobile device interactions include: 1) an understanding of user's attitudes towards multi-user applications in Tent mode; 2) a set of Tent mode interaction techniques; 3) an end-user elicitation of Tent mode interactions; and, 4) a preliminary validation of Tent mode interactions.

2 RELATED WORK

Our exploration of collocated multi-user interactions on a foldable device sits at the intersection of work on (i) nonplanar handheld displays; (ii) collocated multi-user interactions; and (iii) user elicitation studies.

2.1 Nonplanar Handheld Display

Nonplanar handheld displays have long intrigued HCI researchers [52], as these expand the range of potential interaction techniques to include operations such as bending [1, 9, 27, 50, 59, 60] , rolling [25, 48], and folding [7, 10, 24, 34, 48, 54, 70] the device. The ensuing affordances benefit notification UIs [9], viewport transformations [10, 29], and optimize screen real estate [7, 24, 48, 70]. Works such as [15, 62] hint at the possibility of inter-display interactions with flexible digital paper displays. Such techniques enable distribution of a work space based on task priority and user's focus level.

The majority of these works have explored single user interactions, although works like Doppio [54] allow the division of screen resources for sharing purposes by manipulating the display. Also, FoldMe [24] with distinct dual screens has potential for multi-user scenarios. Codex [14] was one of the earliest mobile dual-display systems that allowed the owner to fold it into a convex or battleship form-factor. This offers a unique display to each of the users. We expand on this earlier work, by proposing a broad range of potential Tent mode interactions and applying these towards a large repertoire of multi-user tasks. Marquardt et al. [32] also proposed a convex, bridge form-factor for collaborative use, and implemented a two-player board game where in addition to individual displays for each user, a shared public display is connected at the middle for both players to view. Such multi-display configurations support collaborative sensemaking tasks, a feature we also explore in our investigation.

2.2 Collocated Interaction

Multi-user interaction in a collocated scenario is a well-studied topic within computer-supported collaborative work (CSCW). It has been extensively explored on varying form-factors including tabletops [19] and large wall displays [21, 30, 66]. With the varied and abundant availability of display surfaces, researchers have explored multi-surface and cross-device interactions, for interactions across tabletops, walls, and handheld displays [6, 33]. Among them, collocated interactions on handheld devices are unique as these can operate using off-the-shelf devices, and therefore support ad-hoc collaborative tasks [47]. Researchers have explored the use of multiple handheld devices to assist with collaborative tasks, from methods for connectivity [13] to spatial cross-device gestures [22, 31, 33, 43, 69]. However, it is shown that the use of individual handheld devices in small groups for collaborations negatively affects communication and engagement compared to traditional pen and paper usage [11] as well as causing loosely-coupled interactions, leading to less efficient decision making and group performance [2, 19]. Very few works have extended our knowledge of sharing a single device for collocated interaction [3], which we explore on a single foldable device as Tent mode.

We seize the opportunity for developing an understanding of ad-hoc collocated collaboration on a device that folds, in Tent mode, as it naturally lends itself to multi-user scenarios. The unique aspect involves the ability to separate the space for individual and shared work simultaneously, as Tent mode provides both a personal display (the primary and secondary displays) and a collaborative space (the Edge display). Collocated interaction often requires a mix-focused collaboration method, in which the respective users switch between individual and collaborative work until they reach the goal [16]. The Edge display on the hinge of Tent mode positions itself as a natural space for placing shared content and interactive elements, while the two main screens provide space for individual work. Such workflow involving both private and public spaces are ideal in collaborative interactions [2, 49, 56]. Works on multi-device and multi-display settings have shown the positive effect of having an overview device in group settings on better decision making and collaboration. Having such an overview area increases awareness among group members on each others' actions and decreases the mental workload for coordinating tasks [2, 65]. Such works form the basis of our exploration around having a dedicated area on the Edge display as a space for collaboration overview.

2.3 User Elicitation

As foldable devices become commonplace, we can anticipate a host of novel interaction techniques, particularly suited for collaborative tasks. Elicitation studies [64, 67] have gained significant interest as a method for incorporating end-user participation in the design process with the intent of converging toward a user-friendly [38] and memorable suite of interactions. Such an approach has been adopted to elicit gestures in a large number of contexts, including tabletop displays [68], AR applications [42], drones[4], wearable devices[8, 53] and microgesture design [5, 55]. The results most relevant to our work are elicitations for assisting in identifying interaction techniques on novel devices such as those for deformable [28] or elastic displays [63]. Most elicitation studies have been conducted in single user settings, but can also provide insight when involving more than one user at a time. We explore such methods to extract user input for collocated collaborative tasks, providing novel insights into methods for operating a single foldable device but for multi-user scenarios.

3 STUDY 1: EXPLORING THE SUITABILITY OF COMMON APPS FOR MULTI-USER SCENARIOS IN TENT MODE

We first ran an exploratory study to understand users' openness towards using common mobile apps on a foldable device for multi-user purposes in Tent mode. We reasoned that given the personal nature of traditional mobile form-factors, users may shy away from suggesting collaborative scenarios on such devices.

3.1 Study Design

We structured our study into two phases. First, we identified which apps users envisioned using in a multi-user setting (i) on a conventional handheld device, as well as (ii) in Tent mode. Users grouped the provided list of 32 commonly used apps on mobile devices such as apps for messaging, social media, multimedia and productivity [44, 46]. Among the most highly-suggested apps for potential use in Tent mode from phase 1, we then probed participants about the potential f-formations they envision adopting when operating under Tent mode in phase 2. These f-formations were chosen based on a prior work on micro-mobility in cross-device interaction [33].

3.2 Participants

Participants were recruited through a call for participation by a workplace-wide distribution. All participants were employees from diverse departments, and none from the author's department. None had experience with any type of a foldable device. Each participant was compensated with a small gift equivalent to a monetary value of 10 CAD dollars. Both Phase 1 and Phase 2 were conducted in a closed room environment, measuring 4.6m x 3.75m x 2.7m. For the first phase, we recruited 13 participants aged 20 to 47 (M=27.7, SD=7.7), among which 4 were female. Similarly, we recruited 8 participants for the second phase aged 21 to 33 (M=25.3, SD=4.6) among which 5 were female.

3.3 Apparatus

To encourage users' imagination towards using a foldable device, we constructed a system composed of a motion capture component, a projection component, and a paper prototype component. The paper prototype was constructed using a foam board measuring 17cms x 16.5cms, that could be folded. When folded, both primary and secondary display areas measured 7.75cms x 16.5cms and the Edge area measured 1.5cms x 16.5cms. We affixed eight optical markers on the foam board prototype and used ten Optitrack Prime 17W cameras to capture the spatial movements of the foam board. To simulate an actual device, we used an Epson PowerLite 1286 projector fixed at the ceiling. The projection and motion capture

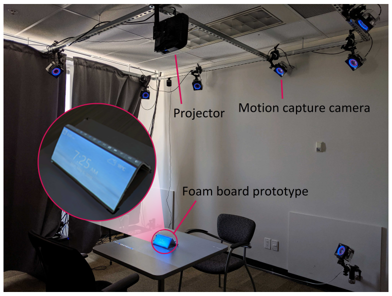

Figure 2: Paper prototype with projection.

components were calibrated such that the graphics were projected on the prototype (Figure 2). On the software side the graphics were rendered through Unity, and the projected screen contents mimic those of a conventional handheld display.

3.4 Phase 1 Procedure

Within each session, each participant first filled out a consent form and socio-demographic questionnaire. The participant was then given the list of 32 apps which were represented by print-out cards to identify apps that they had experience with in a multi-user scenario on a conventional handhelp device (Figure 3 a). Participants were then given an actual device (tablet/phone) with pre-installed popular apps to simulate the participants' usual sharing behavior. We then showed participants the foldable foam-board prototype. The experimenter gave brief explanations of what a foldable device entails, including Tent mode. The participant was encouraged to interact with the prototype and perform folding actions to set it in Tent mode. To facilitate participants' imagination, we projected an image onto the prototype that splits a single display screen into two, when the device was folded. The participant was then asked to identify apps that they perceive could be used in Tent mode for multi-user interactions (Figure 3 b). During the study, the experimenter asked semi-structured questions to probe the participant's thought processes. Each session took about one hour and was videotaped.

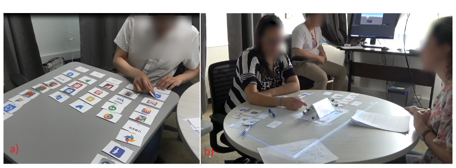

Figure 3: a) Participant sorting the flash cards representing common apps as to their suitability for multi-user scenarios. b) Interacting with projected content in Tent Mode.

3.5 Phase 2 Procedure

Participants were first presented with a consent form and a socio-demographic questionnaire. The experimenter then introduced the idea of a foldable device using the foam-based prototype as in Phase 1. After introducing the concept of Tent mode and its potential for collaborative scenarios, the experimenter briefed the participants with the findings of the Phase 1 study, including the 5 apps that were identified as being most suitable for Tent mode. The experimenter then introduced 3 f-formations (see Figure 4) to the participant by acting as the person he/she would be collaborating with. The participant was then asked to rank his/her favorite f-formation for each of the 5 apps that was introduced earlier from 1 to 3 (1 being the highest priority). Participants could also choose not to rank an f-formation if they believed it would not be well suited for a certain app. They could also rank two f-formations the same. At the end of this phase the investigator conducted a semi-structured interview to understand the logic behind the rankings as well as the contexts in which the participants chose or omitted a particular f-formation.

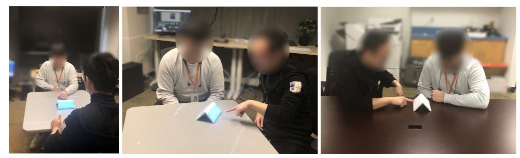

Figure 4: The 3 f-formations introduced to participants. From left to right: Face-to-Face f-formation, L-shaped f-formation and Side-by-Side f-formation.

3.6 Results

3.6.1 *Apps frequently used in multi-user scenarios.*

Apps such as YouTube, Gallery, Google Maps, Chrome, Instagram, Spotify and Amazon were among participants' top favorites for multi-user scenarios. We observed that participants reported on sharing behaviors on conventional devices, such as tilting, similar to [33]. Moreover, we probed potential uses for Tent mode as participants reported that they sometimes lean conventional devices against a wall for multi-user viewing. In the next section we report on how participants envision using these apps in multi-user settings on Tent mode.

3.6.2 *Multi-user scenarios in Tent mode.*

The Popular apps column on Table 1 shows the top 5 apps that were indicated as favorite apps for multi-user settings on Tent mode. Participants' subjective responses can be summarized into the following three categories:

Popular scenarios in Tent mode: In line with participants' previous rankings for Gallery, YouTube and Google Maps as apps that one can interact with in multi-user settings, they explained how those experiences could be transformed to Tent mode.

Managing control access on Tent mode: Participants showed similar patterns for control management techniques on Tent mode. Some participants even asked for a more granular support for control management: *"For Google Photos the guest screen shouldn't have the access to control the screen. Probably zoom-in/zoom-out can be enabled"*. This element of control over one's device resonated with a number of participants and future designs would need to consider methods for toggling across different access control mechanisms when in Tent mode.

Collaboration in Tent mode: Participants envisioned how Tent mode can facilitate collaboration. A "mirroring" functionality to duplicate one screen onto the other was mentioned by all of the participants. Moreover, participants stated that collaborators should be aware of each other's actions so a small floating window could be shown on both sides containing the actions of the other user. Transferring content from one side of the Tent to the other was also among other collaboration features that were desirable.

Table 1: List of popular apps and F-formations identified by the participants for use in multi-user scenarios on tent mode. The popular apps column illustrates the results of Phase 1, and the F-formations column illustrates the results of Phase 2.

	Popular apps (Phase 1, 13 participants)		F-Formations (Phase 2, 8 participants)		
App	**Count**	**Scenario (Quote)**	**Face-to-face as 1st choice (#)**	**L-shaped as 1st choice (#)**	**Side-to-side as 1st choice (#)**
Google Photos	9	*"you can just select and show the pictures you want to share, not every picture"*	*3*	*3*	*2*
YouTube	9	*"we can enjoy different videos, and also, if you go to the washroom, I won't be interrupted, and once you come back you can start at your point in the video"*	***7***	*2*	*2*
Google Chrome	6	*"I search for a Japanese recipe. And he's looking for a Chinese recipe and we just swipe up content to decide what to make."*	*5*	*2*	*0*
Google Maps	5	*"We can save and send pin locations to each other when planning a trip."*	*1*	***4***	*1*
Amazon	5	*"When we are looking for a sofa, we can separately browse and instantly share what we find interesting"*	*5*	*1*	*2*

3.6.3 *Preferred f-formations with Tent mode.*

The F-formations column in Table 1 shows the preferred f-formation for each of the 5 most popular apps chosen by the participants. 7 out of 8 participants chose the face-to-face f-formation as their first choice when using YouTube. When asked, participants expressed that watching video content with the screen right in front of them and not at an angled position is more convenient. Moreover, for 3 of the other apps (Google Photos, Chrome and Amazon) the face-to-face f-formation was preferred over others due to its ability in providing privacy for the owner (only one screen is visible to the friend), enabling users to maintain personal space and divide workload. Google Maps was the only application that was preferred in the L-shaped f-formation over face-to-face since in a trip planning context users might find the need to take a look at the second screen occasionally for better decision making. This input introduced a need to us that in close collaborations, a mechanism should allow users to look at each other's screens regardless of the f-formation. Later in the paper we explore the interactions that support this opportunity in the face-to-face configuration. Generally users picked their favorite f-formation based on factors such as the required proximity with the device, the degree of closeness with the other, or how ergonomically comfortable their interactions were with the folded screens. The latter is the major reason for which the side-to-side f-formation was not among the popular configurations. Our results suggest that the face-to-face f-formation was preferred over the other two, but also that the L-shaped f-formation is not uncommon. The remainder of our exploration in this work focuses on Tent mode in the face-to-face f-formation.

4 TENT MODE COLLOCATED COLLABORATIVE TASK DIMENSIONS

With input from prior literature as well as findings from the first study we describe the dimensions of collocated interactions, specific

Table 2: Dimensions explored in our design of Tent mode tasks: Collaboration Type and the Degree of Granted Control.

		Degree of Granted Control	
		Limited	**Full**
Collaboration Type	**Loosely Coupled**	**T1:** Send restaurant info on Google Maps to a friend who is reading an email, interrupting their current activity. **Application:** Googles Maps	**T6:** You are both editing the same photo individually on each side. Take a peek of your friend's editing results. **Application:** Gallery
		T5: Send 5 photos (view only) to your friend who is reading a web page. **Application:** Gallery	**T8:** You are each looking for recipes on a browser. Create a shared space accessible to both sides for storing interesting recipes. **Application:** Browser
	Tightly Coupled	**T2:** Give dynamic real-time information of your touch points when showing a route to your friend. **Application:** Google Maps	**T7:** Assume you are interested in your friend's editing results. Merge his/her edits with yours. **Application:** Gallery
		T3: Mirror your Gallery page onto the other screen. **Application:** Gallery	**T9/T10:** Add/Remove recipes to the shared space you just created. **Application:** Browser
		T4: Grant scrolling permission to your friend so that he/she can also browse through the Gallery. **Application:** Gallery	

to Tent mode, that we aim to explore in this work. Table 2 shows the 2 dimensions we have identified as a basis for defining 10 collocated multi-user tasks: '*Collaboration Type*' of the interaction and the '*Level of Granted Control*'. These dimensions are inline with that of the literature studying different types of collaboration. For instance, in a work by Koesten et al. [26], collaborative scenarios such as explicit or implicit, tight or loose and synchronous or asynchronous were identified as being common. During our user studies, we observed that users often imagine themselves using Tent mode in multi-user scenarios where both are tightly engaged with the same content or loosely work on different aspects of a task, with occasional updates. Additionally, since collocated collaboration on a single handheld device introduces ownership and privacy concerns, we add *Level of Granted Control* as the second dimension to our exploration as many users provided feedback suggesting a more fluid collaboration in the presence of a control mechanism, i.e. to what degree can the other user change content. Control and ownership of data has also been previously identified as a collaboration dimension by Isenberg et al. [20] along with managing information across displays and mechanisms for data replication. The notion of maintaining personal space and data also exists in other types of single device collaborations, such as on tabletops. However, users' f-formations around the table often dictates the degree of one's personal space relative to that of others [41].

We believe this dimension ought to be included in collocated collaborative scenarios, involving a single device, given the personal nature of these devices in contrast to tabletops. We therefore included 2 levels of granted control in Table 2: Limited control and Full control for the guest user. In Limited control, the owner allows the guest user to change aspects of the viewport, such as scrolling in a limited way. In the Full control mode, the guest user has all the **same privileges** as the owner and can choose to edit and delete content. Full control level is analogous to when a user hands over his/her device to another. Whereas the limited level of control, represents cases wherein the owner may simply show the other his/her screen, and allow limited or no input.

The second dimension referring to either a Loosely coupled or Tightly coupled interaction is defined by the degree to which both users are operating on the same activity. In case of the Loosely coupled operations, the two users may be performing other functions prior to entering into a coupled engagement. In the case of Tightly coupled activities, the two users would be working on the same activity. We note that while other types of organizing tasks may also prove fruitful, we chose these categorizations based on our observations from the exploratory study.

We chose three out of five applications (Table 1) to give the multi-user tasks (T1-T10) a context, which are Google Maps, Gallery and Browser. In Google Maps (T1, T2), the owner sends restaurant information to the friend who is reading a web page on her side of the screen, and shows real-time touch information for route selection, respectively. In Gallery (T3-T7), users send photos to the other screen, grant scrolling permission to the secondary screen, edit photos individually and merge editing results. In Browser (T8-T10), users search for recipes and store them in a dynamic shared place accessible to both users for adding and removing items.

5 TENT MODE INTERACTIONS

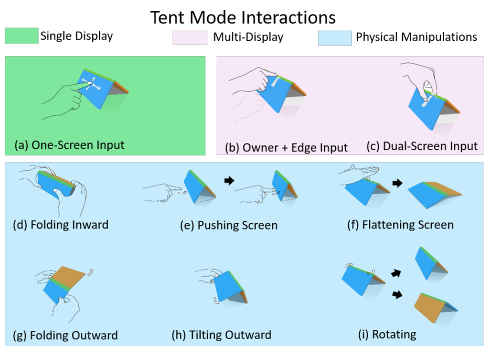

Figure 5: Interaction Design Space

We next investigated how the aforementioned collaborative tasks could be facilitated by Tent mode properties. The three Tent mode sub-displays (primary, secondary and the Edge display) offer new spatial relations among these regions. Prior works on multi-display systems such as [14, 32] introduce design spaces for multi-screen devices for both individual and collaborative use. The "Battleship" form factor discussed in these earlier works is identified as suited for collaboration, however, further mechanisms on how such formation can support collaboration is needed. A work done by [28] inspired our design space in terms of gestures that users intuitively perform on deformable displays such as folding/unfolding and swinging actions. We build upon such interaction ideas and tailor them to collaborative scenarios in our design space. From observations of our exploratory study, as well as the aforementioned prior work, we identify three axes in our interaction design space, each containing a number of techniques (Figure 5) aimed at facilitating collocated interaction.

Single display interactions: on a single screen, the interaction is similar to conventional devices such as swiping and tapping. One unique attribute is the choice of one of the three screens on which the interaction takes place, i.e. either the Primary, the Secondary or the Edge displays.

Multi-display interactions: these interactions span beyond the single display to include 2 or all three sub-displays. This includes techniques such as scrolling from one screen to an adjacent one, simultaneously tapping two screens or even moving items to the Edge display. These interactions may be suitable for transferring content across sub-displays or for merging the workspace by, for example, pinching both the primary and secondary screens.

Physical manipulations: finally, we identify a suite of physical manipulations on the device. This includes *folding*, *flipping*, *rotating* or *tilting*. Folding interactions function by altering the physical form factor of Tent mode, such as transitioning between Tent mode and a tablet. Folding can occur inward or outward. Rotating is an intuitive interaction as it functions similar to conventional devices where we rotate our screen to show others. Tilting interaction has been featured in cross-device interactions to transfer content across users [33]. Tilting incorporates both an exclusive and directional sense such as tilting towards the other user, or towards oneself.

6 STUDY 2: PARTICIPATORY DESIGN

Our exploratory study fed into the design space for mobile ad-hoc collaboration tasks. However, as noted in [38, 39], complementing such outcomes with end-user input may yield a preferred and memorable gesture set. Following this principle, in a paired-user participatory design study, we explored how users might associate collocated collaborative tasks with Tent mode interactions.

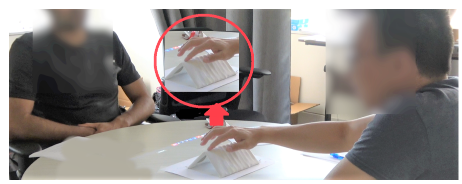

Figure 6: Paired participatory design study

6.1 Study Design

We adopted a methodology similar to that used in elicitation studies [67] to probe and observe participants' behavior in a collocated collaborative scenario. We structured the study tasks (referents) as close as possible to everyday life scenarios and designed these tasks around the most frequently used multi-user apps as reported in our exploratory study. Participant pairs would take turns in assuming a role, either as the mobile device owner (primary user), or the one that information is shared with (secondary user).

Each user suggested their set of gestures, for each referent (see Figure 6). Moreover, as legacy bias is known to influence such outcomes [36], we adopted the production, priming and pairing techniques proposed in [36] (see Procedure section).

6.2 Apparatus and Participants

We recruited 28 participants, all participants were employees from diverse departments, and none from the authors' department. Their ages ranged from 21 to 50 (M=31.7, SD=8.65). We paired them into 14 groups. We had 6 female pairs, 3 male pairs and 5 mixed-gender pairs, none from our exploratory study. We used the same foldable paper prototype and motion capture setup from the exploratory study. The optical markers on the prototype were removed after projector calibration to allow for more natural movements during the user elicitation. The study was conducted in the same room as the exploratory study and each participant was compensated with a small gift valued at 15 CAD.

6.3 Procedure

Participant pairs sat across each other at a table and filled out consent forms and socio-demographic questionnaires. Next, the experimenter briefed the participants about proposing interactions for each task while imagining the device being used in Tent mode. Here we also used the priming technique by having the experimenter demonstrate the interactions illustrated in our design space (Figure 5) on the prototype. Afterwards, each participant was asked to take approximately 2 minutes to familiarize themselves with the prototype. Participants were encouraged to ask questions regarding the range of interaction possibilities. The experimenter asked participants to imagine that the person who is sitting in front of them is a friend who they would feel comfortable sharing the device with. The foam-board prototype was then affixed in a pre-calibrated location on the table between the participants and set into Tent mode. The content for the first referent was then projected, e.g. map on the primary screen and browser on the secondary. The experimenter explained the task, and prompted the participants for their suggested interactions while turning off the projection to mitigate the gulf of execution [18]. One participant was randomly chosen as the primary user first for the first task, followed by the other participant as the primary user for the same task (pairing technique), and the order was swapped for the next task. Here we also used the production technique by asking participants to generate at least two techniques. Once all gestures were noted, each participant ranked their favorite methods. The content for the next task was then projected and the process was repeated. Each session took about one hour and was videotaped. We designed 10 unique collocated tasks (T1-T10) based on the collaboration dimensions (Table 2). To avoid long sessions, Maps, Gallery and Browser were chosen out of the 5 popular Tent mode apps (Table 1) since Gallery and Youtube had similar use cases, and Browser and Amazon provided similar Search UI capabilities. The collaboration scenarios were defined within the context of these apps.

7 RESULTS

In total, participants proposed 424 interactions. Of the proposed interactions, 20 were eliminated from the analysis since they were either misunderstood by participants or included techniques that were not unique to Tent mode, e.g. finger printing techniques to authenticate the owner/guest permissions, voice control or mid-air gestures.

7.1 Gesture Set Observations

In our first analysis, we categorized the 404 interactions based on the design space described in Figure 5. 193 of the recorded interactions were grouped under the Single Display category, 128 in the Multi-Display category and 83 records in the Physical Manipulations category. Given the open-ended nature of the tasks we further grouped and coded the elicited interactions within each category as shown in Figure 7. Entries coded as 'Swipe' refer to the traditional

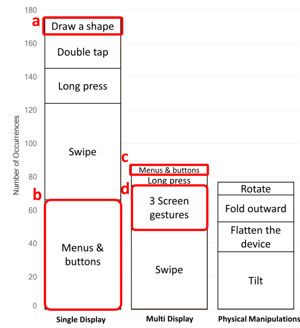

Figure 7: Distribution of interaction techniques identified by participants grouped along the three axes of our Tent mode interaction design space.

swipe gestures on touch screens. The '3 Screen Gesture' group refers to interactions that involve all 3 sub-displays in Tent mode. Note that 3 Screen swipes are not coded under the Swipe group since they allow us to make a distinction between traditional one-screen swipes and Tent mode specific swipes. Based on these groupings, we highlight the following observations.

7.1.1 Agreement Scores. Based on the categories in Figure 7, the agreement scores of the elicited interactions within each group are computed using the equation (1) proposed by [67]. In this equation, r represents one of the 3 categories mentioned in Figure 7 in the set of all categories denoted as R, P_r is the total number of elicited gestures for category r, and P_i is a subset of P_r all coded under the same group.

$$A = \frac{\sum_{r \in R} \sum_{P_i \subseteq P_r} \left(\frac{|P_i|}{|P_r|} \right)^2}{|R|} \cdot 100\% \quad (1)$$

The agreement score of the elicited gestures within the Single Display category is equal to 28.02%, Multi Display reached 41% and the Physical Manipulation category reached 31%. The Single Display category showed the lowest agreement score which is mainly due to users' expertise with traditional one-screen displays and thus provided a multitude of interaction alternatives. The Multi Display category shows the highest agreement score which is indicative of techniques that are semantically related to the given task.

7.1.2 Contextual shapes for collaborative tasks. While many of the interactions were proposed for on a Single display, we noted a peculiar category, shown in Figure 7.a. Users proposed 11 interaction techniques based on drawing a contextual shape for a collaborative task. For instance, participants suggested drawing an 'S' to share a screenshot, an 'M' to mirror their display, a '+' sign to merge photo edits. Such shortcuts could be readily available when the device detected it was in Tent mode. Users' proposed shortcuts also included letters but were symbolically different than those identified by Poppinga et al. [45] as in the latter the authors focused on single user mobile app shortcuts.

7.1.3 WIMP interactions are less favored in multi-display input. From Figure 7.b and 7.c, 66 of the proposed interactions (34%) within the Single Display category include WIMP based (menu/icons) techniques. This number is reduced to 8 interactions (4.5%) within the Multi-Display category and reaches 0 in the 'Physical Manipulations' group (by definition). This finding suggests that fewer menu-centered interactions are adopted as users transition from interacting with a single screen to new interaction spaces such as Tent mode.

7.1.4 Physical manipulation techniques in Tent mode. As seen in Figure 7 physical manipulations, including tilting, unfolding, folding outwards and rotation of the device were among the most popular gestures selected for this category. It should be noted that the interpretation of these manipulations in Tent mode has a new meaning compared to traditional handheld devices. For instance, rotation on a regular tablet often switches between landscape and portrait orientations, however rotating a folded Tent mode was mapped to mirroring the main display onto the secondary display.

7.1.5 3-screen gestures in the Multi-Display category. Aside from Swipe's popularity in the Multi-Display category, 3-Screen Gestures were also included in 27 instances (21%) of the proposed Tent mode interactions (Figure 7.d). Based on our findings these gestures were mostly chosen when they could be semantically mapped to the task. For instance, as shown in Figure 9 participants preferred the pinch-swipe gesture towards the Edge display for task T7 (Table 2) as it resembles merging semantically.

7.2 The Interplay between the Input and Output Sub-Display

Based on the classification of our tasks into the tightly coupled and loosely coupled categories, we were able to analyze our results to understand how the collaboration type affects the suggested interaction techniques. Table 3 shows the interplay between the input and output design space based on the collaboration type. Each cell in the table represents the number of elicited interactions (out of 404 recorded techniques) based on the display region that the interaction was initiated on (Input Display) and the region showing the outcome (Output Display) for our interaction design space (Figure 5).

7.2.1 Choice of Primary, Secondary and Edge displays. As shown in Table 3 it is evident that the highest number of interaction techniques suggested for tightly coupled collaboration falls under the Single Display category. 19% (40 records) of the recorded techniques for tightly coupled tasks get initiated and displayed both on the primary screen. However, for loosely coupled tasks, 27% (41 records) of the techniques were recorded with the primary screen as the input and the secondary screen as the output display. The reason for the contrast in the choice of output display for tightly vs. loosely coupled tasks lies in the need for group awareness. In a loosely coupled collaboration scenario, the owner tries to send information on the secondary screen either in the format of a notification or a small floating window so that the other person's activity would not get disrupted. Moreover, it is also noticeable that the second most preferred method in loosely coupled collaboration adopts the use of the primary display as the input screen and the Edge display as the output (31 records or 20%). This finding is particularly interesting since, even though participants had not been previously exposed to a foldable device with an Edge display, utilization of a tertiary, shared screen that is accessible to both sides seemed helpful in supporting the coordination of collaborative tasks.

Table 3: Interplay between the Input space (where the interaction starts) and the Output space (where the outcome is shown) based on the collaboration type (TC: Tightly Coupled, LC: Loosely Coupled). Each cell represents the number of interactions recorded for the given task. Highlighted cells represent the most prominent interaction spaces based on ratings.

		INPUT DISPLAY: SINGLE DISPLAY INTERACTION (out of 193)			INPUT DISPLAY: MULTI-DISPLAY INTERACTION (out of 128)			PHYSICAL MANIPULATIONS (out of 83)
OUTPUT DISPLAY		Primary	Edge	Secondary	Primary	Edge	Secondary	
Primary	TC	**40**	1	1	0	17	1	**24**
Primary	LC	20	5	0	0	9	7	13
Edge	TC	0	13	0	7	1	0	1
Edge	LC	0	1	0	**31**	0	0	3
Secondary	TC	**37**	14	0	15	2	1	**32**
Secondary	LC	**41**	2	0	10	1	0	6
Total		138	36	1	63	30	9	79

7.2.2 Collaboration type affects physical manipulation of the device. Another interesting finding shown in Table 3 is that even though participants did not have prior experience in manipulating the physical properties of Tent mode as a means of interaction, those techniques were chosen in multiple instances. For example, in tightly coupled collaboration scenarios 27% of the suggested interactions included some sort of a physical manipulation of the device. However, it is evident that this is not the case for loosely coupled collaboration tasks with only 14% of suggested interactions in total. The reason for this variation lies in the difference between tight and loose collaborations. Many users avoided device manipulations since it could distract the secondary user's activity.

7.2.3 Edge display both as a container and a menu. Based on the task, participants showed interest in utilizing the Edge sub-display for placing controls or menus, or to place relevant content to be shared by both users (see Figure 8). Edge display was mentioned as a suitable container 57 times by the participants compared to 58 for placing shared items on main screens. Moreover, in 26 cases the Edge display was picked as a promising place to store menu settings whereas main screens were selected 36 times. This finding suggests that reserving a specific shared space on devices in collaboration settings is important.

7.3 Highly Preferred Interactions

In Figure 9 we present the popular interaction techniques specified by our participants for each task. For example, for task T1 the participant initiates a two-screen swipe interaction starting from the primary screen and ending on the Edge display. A notification containing the information about the restaurant will be shown on the Edge display as the result of this action.

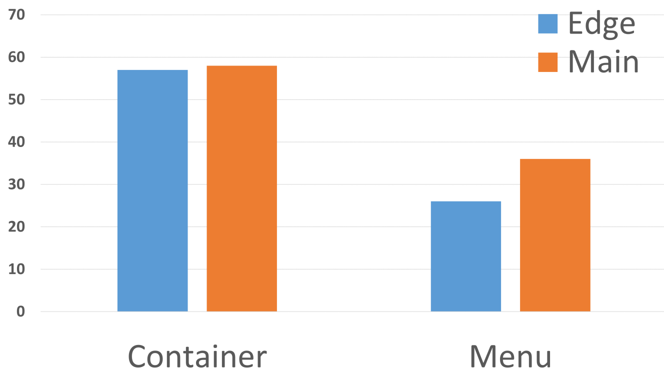

Figure 8: The Edge display compared to other areas of the display for use as a container or for menu input.

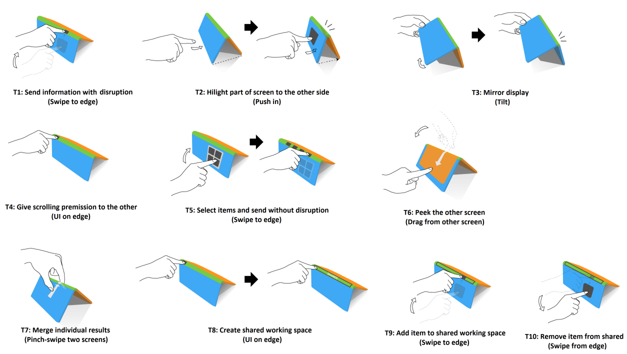

Figure 9: Exemplar popular gestures for each task.

8 IMPLEMENTATION AND PRELIMINARY USER FEEDBACK

To evaluate the findings of the previous two studies, we implemented the interaction techniques in Figure 9 on the projection-based apparatus as in the previous sections. The purpose of this evaluation is to shed light on the value of the proposed interaction techniques as well as the design requirements for future generations of foldable devices. We implemented : 1) folding from a flat posture to Tent mode to initiate and divide collaboration tasks; 2) swiping between private screens and the Edge display to store or retrieve an item to a shared list; 3) swiping on the Edge display to delete items; 4) tilting to mirror and un-mirror the two displays; 5) three-screen swipe to peek at the other's display; 6) strong push of the primary or secondary screens for highlighting content on the other side. These 6 techniques covered most of the interactions in Figure 9. Since T4 & T8 were similar (tap on Edge), they were implemented under the third task mentioned above. We captured all motions, the display and user fingers using an OptiTrack motion capture system. We invited 6 participants aged 21 to 32 (M=24.4, SD=5.3) to experience the system in a scenario where two people are collaboratively planning a trip and involve selecting from a list of hotels to generate a candidate list, checking each other's selections, each looking at the details of hotels on a map, and reaching a consensus.

8.1 Results

Participants were asked to provide feedback about their interaction experience after finishing each scenario. Overall, they commented that Tent mode offers unique interactions that facilitate efficient communication, which we summarize below.

8.1.1 Interactions on the Edge display. Participants felt comfortable with dynamically adding and removing items on the Edge display and reached a consensus quickly: *"It's clean and the text orientation helps to divide the workload"*. Moreover, swiping on the Edge display to delete an item was among the top favorite techniques: *"I like sliding [horizontally] on the Edge display! It feels nice"*.

8.1.2 Physical movements of the device. The Tilt to mirror technique received positive feedback from participants such as: *"It [tilting] makes sense"* or *"It's intuitive"*. However, participants also expressed that the system should provide confirmation after the tilt since they cannot see the secondary screen. Furthermore, some participants stated that performing a strong touch on one screen to highlight information on the other side could move the device and distract the other person.

8.1.3 Performing multi-screen gestures. Taking a peek at the other screen received mixed feedback from our users. Some described it as an intuitive gesture but others stated that performing this gesture might distract the other person.

9 DISCUSSION

We discuss implications of our outcomes and limitations of our exploration which we intend to address in future work.

9.1 Use of Edge display in collaborative scenarios

A shared, common display is well known to support a number of collaborative tasks [2], but to date has primarily been investigated on larger displays. Inspired by such earlier results, our exploration of collaboration on Tent mode, included a shared display, the Edge display, which appears at the intersection when both screens are folded. Our study findings show that including such a shared workspace on the device facilitates loose and tight collaborative scenarios. Users suggest using such a sub-display as both, a container for placing items to be shared, as well as for placing menu items. Furthermore, scenarios which require continuous feedback and input from the other also benefit from having a shared sub-display within view.

We find that loosely coupled collaborations usually lead to a heavier use of the Edge display as a container compared to tightly coupled scenarios. The reason for this difference lies in the fact that in tightly coupled scenarios users are generally more aware of each other's states and they can just swipe up information to be directly shown on the other side. However, in loosely coupled scenarios, participants often adopt a two-stage sharing mechanism, in which they first put the item on the Edge display similar to a waiting list and whenever the other party finds it suitable s/he chooses the item from the Edge and enlarges it.

On screens that do not offer an Edge display, we believe an 'edge-like' display could benefit collaborative interactions. Such a display could be replicated on both screens, and does not need to assume a large size for being useful. In our case, the Edge display was 1.5cms × 17cms, and despite its small size, it was found to be beneficial to users' activities. This is analogous to the application bar used on many operating systems, including Windows and the Mac OSX.

9.2 Enabling physical manipulations on foldable devices

Our proposed interactions included physical manipulations, such as tilting, rotating, flattening, of the folded device. Interestingly, users identified numerous usages for these interactions, with tilting the display towards the collaborator as being the most frequently chosen method (Figure 9.T1). Furthermore, our study results suggest that physical manipulations are preferred when users are assured that the device movement will not distract the other party. Moreover, since moving a device can put a strain on users' flow, this interaction method should be used in situations in which the physical interaction can be semantically connected to the expected outcome. As an example, for task T3 one participant stated that she was hesitant to physically move the device, but if the opposing screen is not in use she prefers tilt: *"... in this case tilting. Because I'm not distracting anymore"*.

Physical manipulations were also preferred when the two wanted to achieve a shared goal simultaneously. In T7, they decide to merge their photo edits together. Participants were comfortable to move the device since they both had full awareness of each other's actions and decisions.

9.3 Tent mode applications

As we have observed through our user studies, Tent mode of a foldable device offers several advantages in collocated multi-user scenarios. Here we conceptualize a few potential application scenarios

9.3.1 Fluid content sharing. Sharing content on our personal devices with a friend has inconveniences such as having to change orientation and privacy concerns. Tent mode provides fluid content sharing mechanisms where orientation is preserved without handing over the device, while the device owner can maintain ownership and privacy. Furthermore, our exploration reveals that users are willing to adopt Tent mode in a number of different f-formations, aside from being face-to-face, such as when sitting in the L-Shaped or side-by-side f-formations.

9.3.2 Competitive gaming. While we have not explored collocated gaming scenarios in our second and third studies, gaming was a popular scenario that arose in the exploratory study. As Tent mode offers private displays for both users, it is well-situated for competitive gaming such as Battleship and Scrabble [32].

Moreover, physical manipulations of the device could offer richer interaction experiences, e.g. each user holding their own private display with their hands would create a volume under the Tent where physical interactions could happen beyond traditional UI based gaming.

9.3.3 Communication bridge. Our personal devices have become inseparable from our daily activities and can often lead to a social disconnect [40]. With Tent mode, we envision end-users may enhance their collocated communications as it provides an opportunity for mutual interactions.

9.4 Limitations and Future Work

Tent mode partitions two personal displays facing in the opposite directions, which gives the intuition of interactions where two users would be in a face-to-face f-formation [33]. Nonetheless, our initial findings on five popular apps hint at the potential of Tent mode being desirable in the L-shape and side-by-side f-formations [33, 57]. The results can also generalize to more than two users as well as additional f-formations with larger display sizes allowing for more viewing angles. In future work, we intend to explore the varying potential folding structures with varying group sizes. This is possible through novel dynamic folding mechanisms [28] or through spatially orienting displays to accommodate users in different positions, such as in SurfaceConstellations [32].

In our exploration, we used a foam-board prototype to identify how users may engage with a foldable device. This offers the advantage of not being limited to interactions that they may be familiar with, also known as the legacy bias [36]. However, in future work, we intend on prototyping the emerging interactions on a consumer-grade foldable device to examine the feasibility of many of these techniques. Moreover, with the unveiling of larger-scale foldable devices such as those from Lenovo and Dell, we plan to validate if our proposed Tent mode techniques scale to these large form-factor foldable devices.

Given earlier work on folded display interactions [14], our study design primed users with a number of existing interaction techniques. While priming is a common method to solicit creative input from users [36], it may also limit some to only generating interactions based on the materials used in the priming. We intend on carrying out in-field explorations to address this aspect of research.

10 CONCLUSION

In this paper, we present Tent mode, a form factor for foldable handheld devices that facilitates collocated multi-user interaction. Through an exploratory study, we gained insights into users' behavior for multi-user interaction on conventional mobile apps in Tent mode. Through a participatory design study, we elicited a range of interaction techniques based upon the unique properties of Tent mode. Our findings suggest that including an Edge display for placing shared items enriches the collaboration experience. Moreover, physical manipulations in Tent mode were adopted as an interaction method particularly suited for tightly coupled collaborations. We envision that our conventional collocated interactions could be significantly enhanced by the emergence of foldable consumer electronics and the adoption of Tent mode operations.

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