

Proxemics Beyond Proximity: Designing for Flexible Social Interaction Through Cross-Device Interaction

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ABSTRACT

Cross-device interactions enable ad hoc sharing of content and control in co-located collaboration. Cross-device research often draws from proxemics theory for designing interactions based on detection of spatial relations such as distance and orientation between people and devices. However, detection of human-human or human-device proximity also constrains flexibility in co-located social interaction. We suggest a proxemics-based approach to designing flexible cross-device interactions. From observations in a field study, we articulate how co-located sharing practices are shaped by the interplay between everyday mobile devices and the physical environment. Based on these insights, we present three cross-device prototypes as proofs-of-concept, demonstrating three design sensitivities for considering proxemics beyond proximity; incorporating features in the environment, enabling flexibility in interpersonal distance and orientation, and providing multiple alternative action possibilities. Drawing from characteristics of our prototypes, we discuss concrete proposals for designing cross-device interactions to enable flexible social interaction.

Author Keywords

Interaction proxemics; ad hoc collaboration; sensing systems; proximity sensing; cross-device interaction

CCS Concepts

•Human-centered computing → Human computer interaction (HCI); HCI theory, concepts and models; Social content sharing; Ubiquitous and mobile computing;

INTRODUCTION

Today, people use personal mobile devices such as laptops, tablets and smartphones in a variety of social and physical settings for sharing digital content and control with each other. Yet, ad hoc sharing between personal devices is still a challenge for people who are not already connected. This has led

to research on cross-device interaction [30, 15], proposing a range of interactive sensing systems (e.g., [13, 52, 41]) that provide collaborating actors with the ability to share across each others' devices in an ad hoc manner. Many of these systems draw from the framework of Proxemic Interaction by Greenberg et al. [24], building on proxemics [28]; theories on people's social use of space. The framework provides an overview of proxemic variables (such as distance and orientation) for detection mechanisms in context-aware systems.

However, detecting such spatial relations may also constrain the flexibility in social interactions. In this work, we propose to consider *Proxemics Beyond Proximity*, switching focus from detecting proximity (e.g., distance and orientation) to enabling interpersonal relations by designing for a flexible interplay between people, interactive devices and features in the environment (e.g., tables). We demonstrate the approach via three prototypes for cross-device interaction (see Figures 1-3).

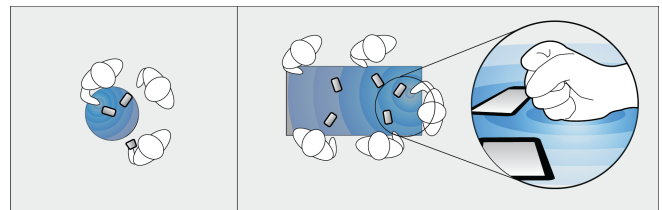


Figure 1. Slam-to-Share: table properties define boundaries for sharing

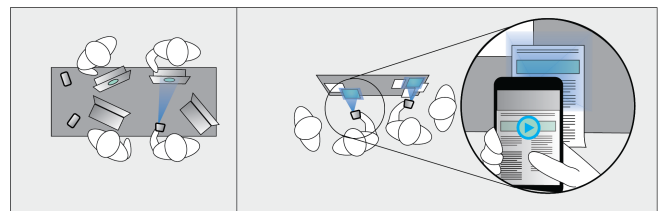


Figure 2. Stick-to-Share: paper artifacts are mobile digital access points

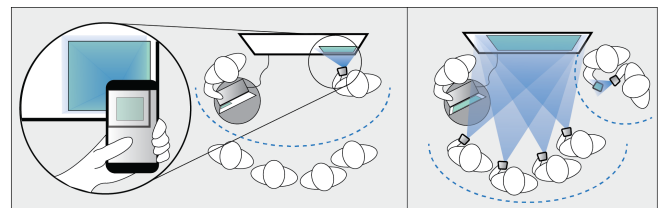


Figure 3. Show-to-Share: resizing tags changes sharing possibilities

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Our work builds on prior proxemics-informed HCI research (e.g., [43, 46, 35, 25, 26, 57]) that conceptualizes interactive systems in terms of how their properties work in an *interplay* with the environment of fixed (e.g., walls and ceilings) and semifixed (e.g., tables and chairs) features to configure interpersonal relations. Extending this line of research, we contribute three design sensitivities for considering proxemics beyond detection of proximity relations:

1. Incorporating fixed and semifixed features of the environment to constrain and enable action during collaboration
2. Enabling flexibility in interpersonal distance and orientation during sensor-based interaction
3. Supporting multiple alternative manipulation opportunities to achieve the same effect

Together the sensitivities serve as a lens, helping future designers and researchers to operationalize proxemics for designing flexible cross-device systems. They are elicited and refined via a research-through-design approach [10, 14, 7]. Brudy et al.'s cross-device survey welcomes research that unifies empirical and technical work [15]. Our work particularly triangulates between *proxemics theory*, *empirical studies* of co-located sharing practices, and *prototyping* cross-device interactions.

The paper is structured as follows. First, we outline related work on proxemics and cross-device interaction. We then present our contribution of three design sensitivities. Then follows an in-depth discussion of our design research based on empirical study and prototyping. Finally, we discuss the novelty and broader applicability of the design sensitivities.

RELATED WORK

In the following, we outline related conceptual lenses in HCI based on proxemics theory, followed by an overview of state-of-the-art research on cross-device interaction.

Proxemics as Conceptual Lens for HCI

Our work builds on Edward T. Hall's proxemics theory [28]. Through the lens of proxemics, we come to see social relations as affected by and readable in people's spatial organisation. Famously, Hall describes interpersonal space as enacted through *proxemic zones* (e.g., via distances between people divided into ranges concerning intimate, personal, social and public encounters) that provide different opportunities for social action. Furthermore, Hall describes how features of the environment have significant impact on interpersonal relations, e.g., furniture arrangements affect people's social interactions.

These ideas have gained traction within HCI research. Most relevant to our work is the framework of Proxemic Interaction [24, 6] that operationalizes proxemics for context-aware systems to have fine-grained system knowledge of *proxemic dimensions* (distance, orientation, movement, identity and location) based on sensor input from devices and room equipment. The framework then acknowledges that proxemics is more than proximity, yet focuses primarily on *detecting* human-human or human-device relations, e.g., for interaction with large displays [24, 6] or across multiple devices [41, 19], where the interface implicitly responds to user actions. For instance, the Proxemic Presenter [24] detects a user's distance

and orientation to a display to respond with different interface transitions, e.g. bringing up personal notes or slide controls when a presenter faces the display. While these systems offer interesting contextual adaptations, implementing such rules can sometimes be constraining due to the particularity of social and physical contexts in which interaction takes place [20, 23, 54, 35]. For instance, in unlocking slide controls, Proxemic Presenter also requires the presenter to face away from the audience in order to control the slides.

Another strand of proxemics-informed research draws on the conceptual lens of Interaction Proxemics [46, 35, 25, 43, 26, 57], which provides a complementary approach to Proxemic Interaction. Instead, it focuses on the *interplay* between interactive technologies, interpersonal relations and features of the environment. In particular, O'Hara et al. [46] argue that the design of an interactive system has *proxemic consequences*: people's spatial organization is *enabled* and *conditioned* by the system's interplay with its physical environment to encourage or inhibit certain social and collaborative behaviour. They further argue that in order to design for effective collaboration, we must consider how interactive systems and design of workplace environments mutually frame social actions.

Our contribution builds on the conceptual lens of Interaction Proxemics [46, 35, 25, 43, 26, 57], contributing design sensitivities specifically for enabling flexible social interaction through cross-device interaction.

Systems for Cross-Device Interaction

The research area of cross-device interaction has contributed interactive systems that let users transfer content and control across nearby devices. Such systems have the potential to enable new forms of collaboration with fluid transitions between activities [30] by supporting ad hoc content sharing (e.g., GroupTogether [41] and FlexiGroups [33]), interaction in meetings based on mid-air gestures (e.g., CodeSpace [13] and HuddleLamp [52]) or wireless control of displays (e.g., Office Social [17] and TouchProjector [12]). Many systems deploy a sensing infrastructure to achieve wireless associations between devices in an ad hoc manner – i.e., without being connected a priori. The systems typically deploy external cameras mounted in the environment to enable detection of spatial relations via fine-grained modelling of human-human interactions [24, 39, 41, 60], human gestures [59, 13, 55] or spatial device relations [52, 51, 19].

When considering mobile vs. stationary sensing infrastructure, there are tradeoffs in terms of how they enable or constrain proxemic relationships. Sometimes a fixed tracking area is desirable, but as acknowledged by Houben et al. [30, 15] they also constrain mobile use: stationary sensors are fixed features of the environment, requiring users to organize within particular sensed areas. Furthermore, the detection mechanism has proxemic consequences. For instance, while GroupTogether [41] enables cross-device sharing based on typical patterns of how people organize, it also requires users to stand in discrete orientations and distances to each other while holding devices to reveal intent of sharing. TouchProjector [12] enables wireless control of other displays via mobile cameras, while requiring users to stand within line of sight to the display

that they remotely control. Finally, sensor choices impact people's proxemic relations. For instance, SurfaceLink [22] (using microphones), HuddleLamp [52] (using external cameras) and the Collaborative Workplace Table [48] (using WiFi-based proximity detection) all exploit tables as a semifixed feature to enable ad hoc sharing across devices. The interplay between tables and the utilized sensors then offers different degrees of flexibility for ad hoc sharing: for instance, HuddleLamp requires users to organize around particular tables (with external camera sensing), while SurfaceLink would enable sharing on any surface (requiring only mobile microphones).

Research on cross-device interaction often focuses on *detecting* proximity. We suggest a complementary approach which focuses on *enabling* flexible social interaction through design of cross-device interactions.

RESEARCH APPROACH

Before presenting our contribution in more detail, we outline our research approach. The research in this paper can be described as programmatic design research [10, 14, 7] where an overarching *Question* (Q) is framed by a *Program* (P), explored and informed through *Design Experiments* (X):

Q: Building on a community of research that considers proxemics as a lens on interactive technologies [46, 43, 35, 24, 41], our work aims to understand the following question: *how do the spaces shaped by the interplay between interactive systems and our physical environments condition interpersonal relations, and what does it mean for interaction design?*

P: We extend prior HCI research on proxemics [46, 43, 35] by articulating a conceptual lens of design sensitivities based on the following design goal: *enabling flexibility for enactment of interpersonal relations in the design of interactions for cross-device sharing.*

X: We elicited and refined design sensitivities through prototyping of cross-device systems inspired by a field study of ad hoc sharing. Our three proof-of-concept prototypes demonstrate how to design for *proxemics beyond proximity*.

The design sensitivities presented in this paper have emerged from three overlapping concurrent research activities:

1. Empirical observations of collaboration and sharing practices with mobile devices (laptops, phones, etc.) in a furnished environment (with tables, whiteboards, walls, etc.)
2. Theoretical conceptualization of sharing practices and cross-device interactions in terms of proxemics
3. Designing and prototyping cross-device interactions with mobile built-in sensors for enabling flexible ad hoc sharing

In the following, we unpack the above three research activities and how they link together. We conducted observations of co-located sharing practices in a concrete context. The prototype designs of cross-device interactions (*design*) are motivated by analysis of real-world sharing practices (*empirical*) through the lens of proxemics (*theory*), leading to the contribution of three design sensitivities. The empirical study was structured as follows: Two researchers followed the initial phases of an ICT design project course; a class of 9 student groups (each consisting of 3-5 students), 2 teachers and 4 teaching assistants. Each student group had a dedicated area for organizing

contents and materials throughout the course. Such a setting allowed for observing social use of space (proxemics) in activities for both work in small groups and on-class presentations, where people respond to the opportunities of technology arrangements and the layout of interior elements (such as tables, walls, whiteboards, etc.). Observations were conducted in 4 sessions, each consisting of 3 hours. Sessions followed 4 consecutive classes in the project course, in which students went through the initial phase of identifying a problem in a concrete domain to address through design, and finally present ideas on class. Each session consisted of observation and taking photos (approx. 800 photos) as the primary form of note taking.

The photo material provided real-world inspiration for developing scenarios that bring proxemics of social interaction with interactive devices to the fore. Our observations are viewed through the lens of proxemics, with particular attention to proxemic transitions and dynamics of technology use (in line with [35, 25]). Proxemics then serve as *conceptual glue* [47] between the empirical findings and design rationales. Hence, rather than presenting the empirical findings in a traditional way, the integrated design research approach (bridging often separated activities) lends itself to a discussion of the findings in the context of prototype design rationales. By relating design proposals from design experiments to the theoretical outset (as promoted by Zimmerman et al. [61]), the design rationales of the prototypes serve to both operationalize and articulate the design sensitivities. Hence, while aspects of our prototypes may be similar to prior systems, their purpose here is to help articulate design sensitivities for proxemics that have received less attention in cross-device interaction research.

PROXEMICS BEYOND PROXIMITY

Before describing our empirical and design work in detail, we present the outcome of our work in terms of three design sensitivities, outlining a novel approach to operationalizing proxemics for cross-device interaction.

Fixed and Semifixed Features

Incorporating fixed and semifixed features of the environment to constrain and enable action during collaboration

First, an important point from proxemics theory is that interpersonal relations are not articulated in isolation: interpersonal space (e.g., proximity) is considered within a material world, where people's actions are conditioned and enabled by features of the environment. Hall articulates how fixed (e.g., walls, doorsteps) and semifixed (e.g., tables and chairs) features in the environment provide different means to configure people's social interactions [28]. For instance, re-arranging tables (semifixed) can affect how people have conversations around them, and lecture halls lay out a socio-spatial order (fixed) regarding who is in power to speak (on stage) and who is listening (in seats facing the stage).

While some systems for cross-device interaction are designed to exploit features in the physical environment (e.g., [52]), it is rarely articulated how such features *constrain* and *enable* action possibilities in co-located collaboration. Considering **Fixed and Semifixed Features**, we suggest to have explicit

design rationale for how the cross-device system works together with features of the environment (e.g., sensing is affected by tables and walls) and its social consequences (e.g., people are bound to tables for interacting). We expand on this idea in the articulation of our prototypes. For instance, *Slam-to-Share* (see Figure 1) enables sharing content across devices based on their mutual detection of a slam gesture on a horizontal surface. It considers tables as an explicit and complementary component alongside the device in the configuration of action (e.g., devices can be placed and oriented on tables for opting in and out). This device-and-table interplay allows collaborators to exploit *tables as features in the environment* to flexibly reconfigure their sharing relations.

Interpersonal Flexibility

Enabling flexibility in interpersonal distance and orientation during sensor-based interaction

Second, Hall discusses a design sensitivity regarding how architectural design may support co-located people in flexible enactment of interpersonal relations: "[...] *What is desirable is flexibility and congruence between design and function so that there is a variety of spaces, and people can be involved or not, as the occasion and mood demand.*" [28]. Lawson [36] builds on this argument showing (in studies of office spaces and train coaches) how features of furniture arrangements support the fundamental spatial need for humans to have multiple ways of approaching co-located others. A study on how people commonly distribute themselves around a six-seat table shows that where people decide to sit is significant to how they intent to engage with co-located others, e.g., conversational, confrontational, or (merely) co-existing.

Accordingly, we suggest a need to adopt a stronger sensitivity to **Interpersonal Flexibility** for designing sensor-based interactions by allowing users to *negotiate* interpersonal space in a way that is meaningful to the particular situation. This design sensitivity is particularly complementary to the Proxemic Interaction approach [24]: While Proxemic Interactions have sought to detect particular interpersonal relations through *distance and orientation*, we suggest that it can also be important to consider how our designs allow for *flexibility* in adapting interpersonal distances and orientations. For instance, by utilizing mobile sensors (as opposed to external sensing) the sensing area can be moved by one or more users to different places for sharing. This is, for instance, illustrated by the design of *Stick-to-Share* (see Figure 2). The prototype enables associating a "sticker" (a detectable image on paper) with a digital resource (a URL), accessible via the camera frame in an augmented reality application. It demonstrates how the locational flexibility of the sticker can be exploited for configuring shared access to digital content – both in person-to-person exchanges and in semi-public exchanges, where people co-exist in the same space with the same shared resources.

Multiple Alternatives

Supporting multiple alternative manipulation opportunities to achieve the same effect

Third, we refer to Reeves et al.'s distinction between manipulations and effects [53], where *manipulations* are the actions

carried out by the user of a system, while *effects* are the results of these manipulations. In particular, we are concerned here with cross-device manipulations based on *sensors*, and effects that are '*interpersonal*' (e.g., dyad or group exchanges).

We suggest to adopt a sensitivity towards supporting multiple alternative opportunities for manipulating to achieve the same effect (referred to as **Multiple Alternatives**). This concern is motivated by a study result [45], revealing proxemic consequences of QR tag interaction. The study showed that required closeness to QR tags in the environment sometimes created an awkward social situation (e.g., users had to ask strangers to move). However, providing multiple alternative *proxemic* opportunities for interaction (i.e., dialing a phone number from a distance vs. scanning tag up close) helped some users avoid such situations. We demonstrate how to consider this sensitivity, for instance, through the design of *Show-to-Share* (see Figure 3) – a presentation tool that provides users with a palette of interaction opportunities for distributing wireless control via QR code tags. It illustrates how the ability to show/hide QR tags on displays of different form factors (small, large, mobile, fixed, etc.) allows for multiple alternative ways of interacting (manipulations) to establish the same sharing relation (effect), consequently allowing for flexibility in how control is shared among co-located people.

SLAM-TO-SHARE

With *Slam-to-Share* (see Figure 4), we consider how *mobile devices and tables* can work together to configure people's sharing relations through cross-device interaction.

Prototype

Slam-to-Share is a web app that utilizes accelerometer and gyroscope in mobile phones for detecting an explicit physical gesture of two consecutive slams on a table surface for phones with screens facing upwards. The slamming gesture creates an ad hoc association between multiple users' device ecologies. It exploits the built-in sensing capabilities of people's mobile phones, however, the phones are merely companions for sending and receiving documents that serve best to be manipulated on their laptop. This is supported via personal user accounts, where events are accessible by all devices in one person's ecology through the tap of a "sync" button (that broadcasts messages to any currently open client associated with the same user). The gyroscope is used to only actively respond to slams when the phone is lying flat on the table with the display facing upwards. When two consecutive peaks from user slams are detected by a mobile phone's accelerometer, the user opts in to be associated with other devices on the surface for the exchange. The double-peak detection reliably avoids that devices detect random motion from the table surface.

Empirical: Tables as Semifixed Features for Sharing

The design of *Slam-to-Share* is inspired by how students organized with mobile devices and tables as a feature of their shared space. In our observations, we found that a common act of sharing was for students to invite others to view digital resources on mobile device screens temporarily during conversations (see Figure 5). In each group, laptops were distributed around the group table and could easily be used for sharing

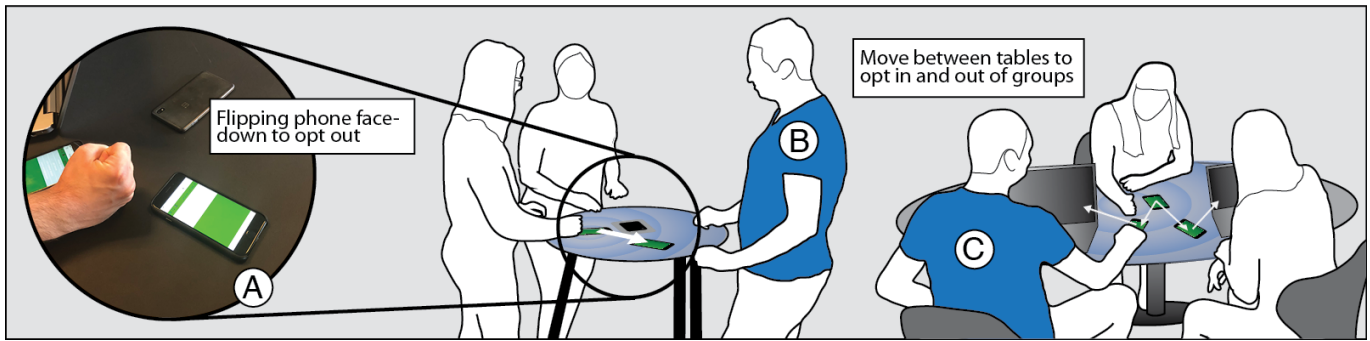


Figure 4. Slam-to-Share detects a slam gesture on devices placed on the same table surface. A: Users can opt out via the gesture of flipping the phone face-down on the table. B-C: Since it uses mobile sensors, devices can be moved between tables to engage in different sharing relations.



Figure 5. Sharing supported by tables. A: A laptop screen (green) is rotated on the table (blue) to show others a document. B: Gathering around a person's laptop screen (green) on one side of the table (blue).

during conversation, and the table supported movements with and around laptops. For instance, in Figure 5(A), a person's laptop is oriented towards others around the table as a gesture for sharing a document on affinity diagrams, during an affinity diagram exercise. In contrast, Figure 5(B) shows a situation where others gather around one person's laptop.

The important implication from these social gestures with laptops on tables is that *the interplay between mobile devices and tables* shapes how users can configure sharing relations. In other words, without the table - the enacted interpersonal spatial relations in these examples would not be possible (**Fixed and Semifixed Features**). Furthermore, the examples illustrate how the students use the features of the table to enact particular sharing relations: in Figure 5(A), the person in the middle has explicitly allowed for others to view screen content by rotating the screen towards them, resting on the table away from him, whereas the laptop screen in the right corner remains a private screen, restricted by the orientation of the laptop and boundaries of the table surface together.

Design Rationale: Sharing by Slamming Tables

We consider a scenario of how Slam-to-Share may augment the interplay between tables and mobile devices for sharing:

In the first week of their project course, Alice, Bob, and Emma sit around a table after having written some notes on project ideas on a whiteboard next to them. They now want to share a slide deck to collaboratively fill in content, and they have not previously shared any digital content. They all have their laptops and mobile phones out on the table. Alice creates a slide deck and syncs it to her mobile phone. They all place their mobile phones on the table. After placing his mobile phone on the table, Bob walks up to the whiteboard to take some photos of

notes on the whiteboard to appear on a slide. Alice does the slam gesture (Figure 4A), broadcasting a link to the newly created slide document. This event syncs to all their laptops through their personal accounts by proxy of the mobile phones (Figure 4B). They start collaboratively filling in content via their laptops,

The teachers are standing at separate tables with their laptops to help students with questions. Bob walks over to talk to one of the teachers, Peter, who currently talks to a student from another group. Peter mentions a handful of publications that might be relevant to the students. During the conversation, he finds them on his laptop, attaches URLs from the laptop version of Slam-to-Share. The students have placed their phones on the table next to his, and he slams to share multiple times. Bob is not interested in receiving a resource that is only of interest to the other student, so he flips his phone face-down to opt out of receiving it (see Figure 4A).

In the sensing design of Slam-to-Share, we incorporate the interplay between mobile devices and tables, creating a sharing relation defined by "*slamming table surfaces*" in the environment (**Fixed and Semifixed Features**). The system requires devices to share the same underlying surface, similar to SurfaceLink [22] and HuddleLamp [52]. Such sharing relations bound to a table enables a group of people to define a bounded area for sharing that does not involve other co-located people.

However, similar to Jokela et al. [33], we suggest that the sensing capabilities should allow for users to appropriate features of the system in response to shifts in social situations, where the spatial needs (e.g., interpersonal distances and orientations) change (**Interpersonal Flexibility**). In contrast to HuddleLamp [52] – which uses external sensing – Slam-to-Share (along with SurfaceLink [22]) utilizes *mobile sensors*, providing the opportunity for moving the space for sharing to different tables, allowing collaborating actors to flexibly engage in different sharing relations. Even though the detection mechanism is bound to a horizontal surface, it supports **Interpersonal Flexibility** because opting in and out of a sharing relation is not bound up in detecting distances and orientations between people and devices. For instance, while the detection mechanism of GroupTogether [41] requires users to hold their devices while sharing (because F-formations are detected together with devices), Slam-to-Share detects devices indepen-

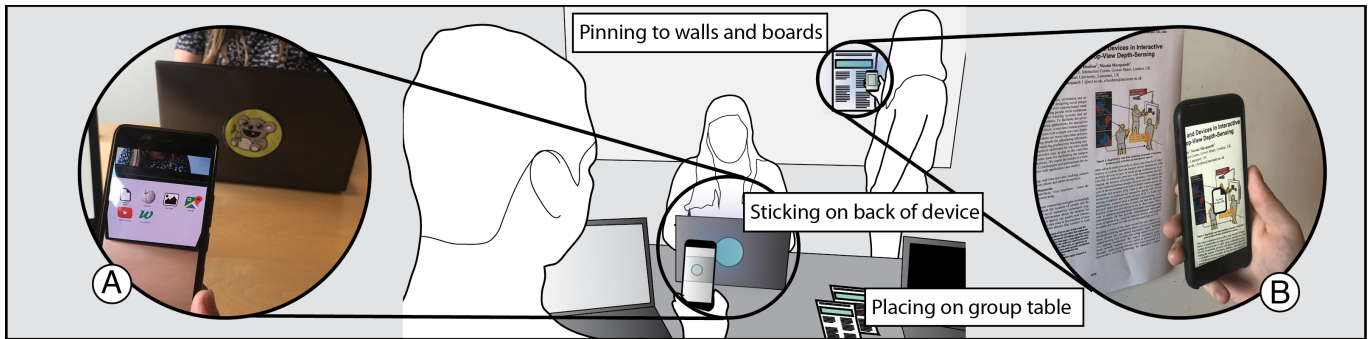


Figure 6. Stick-to-Share exploits mobility of paper artifacts to enable association of content with and juxtapose it to artifacts in the environment. A: A sticker enables digital access, e.g., on the back of a laptop. B: By pinning paper artifacts to a shared space, digital access is persistently available to all.



Figure 7. Mobile artifacts allow for flexible organization, such as, A: juxtaposing laptop displays (green) to paper artifacts on a wall (blue) while others sit at the table with access to individual resources, or B: sitting around a table with whiteboards and books (blue) in view.

dent of their users. This enables Bob to place his phone in the sensed area for sharing and wander off, knowing he opted in.

Finally, Slam-to-Share supports multiple proxemic opportunities for opting in and out (**Multiple Alternatives**): collaborating actors can easily opt out by either picking up the device or subtly flipping it over face down. Such micro-mobility gestures allow for flexible management of sharing relations: e.g., it supports opting out of a share while staying seated around the table, without the need to trigger through discrete distance and orientation thresholds.

STICK-TO-SHARE

Stick-to-Share (see Figure 6) illustrates how mobile artifacts allow for flexibility in interpersonal space, and that fixed features serve as resources for organizing these artifacts.

Prototype

Stick-to-Share uses the built-in camera for detecting images in the camera frame using the AR framework Vuforia's cloud recognition API for creating and detecting image targets [4]. The application is a lightweight platform for associating a URL with an image, which can then be printed and attached to artifacts, effectively distributing interaction opportunities with Stick-to-Share around physical surroundings. A web app enables associating URLs to image targets (processed by Vuforia's feature detection service). A native mobile app (see Figure 6) can then recognize the image targets using the built-in camera and display links to URLs in AR.

Empirical: Mobility Enables Interpersonal Flexibility

The design of Stick-to-Share is inspired by the observation that mobile artifacts such as paper and laptops allow for flexible interpersonal sharing. More specifically (in line with prior

studies, e.g., [49, 37]), our observations show that the ability to manipulate and juxtapose paper artifacts and mobile devices in relation to fixed features enables flexible configuration of interpersonal relations during collaborative activities.

Even though features of the space remain relatively fixed (tables, corkboards and whiteboards), the locational flexibility of paper artifacts and mobile devices allows for collaborators to enact a large variety of interpersonal relations, ranging from addressing one or two others (like in Figure 5A) to an entire group (like in Figure 7A). Yet, it is evident that these features of the environment condition how people can arrange their mobile artifacts. E.g., whiteboards and cork boards are utilized as resources for making access to content persistent through paper artifacts stuck on them. They further allow for sustaining activities where mobile displays are moved in relation to post-its, whiteboard writings and printed materials for having multiple information resources in view (Figure 7). For instance, Figure 7(A) shows how paper artifacts can be organized flexibly by pinning them in juxtaposition to each other, and device screens can similarly be placed in relation to these and rest near the owner during discussions. Furthermore, the situation in Figure 7(B) shows an arrangement where a whiteboard with shared notes (from a previous activity) serves as a conversational resource in a collaborative writing activity, due to its persistent visibility in a fixed location. However, what makes the whiteboard accessible in the given activity, is the *mobility* of the laptops allowing for each person to orient flexibly towards the whiteboard while working. The collaboration is, in this example, coordinated by referring to a shared synchronized document that is open on each student laptop.

Design Rationale: Interpersonal Flexibility via Stickers

We present a scenario for Stick-to-Share, used in conjunction with mobile artifacts for flexible digital exchanges.

Alice, Bob and Emma meet to do a literature review on HCI research in an affinity diagram on the whiteboard. Alice finds a photo of Mark Weiser, the father of ubiquitous computing, with a famous quote on it. She creates a sticker via Stick-to-Share out of the image and associates it with a publication link. She prints the sticker and hangs it next to the affinity diagram.

The following week, they discuss the affinity diagram on the whiteboard. They are suddenly unsure about some

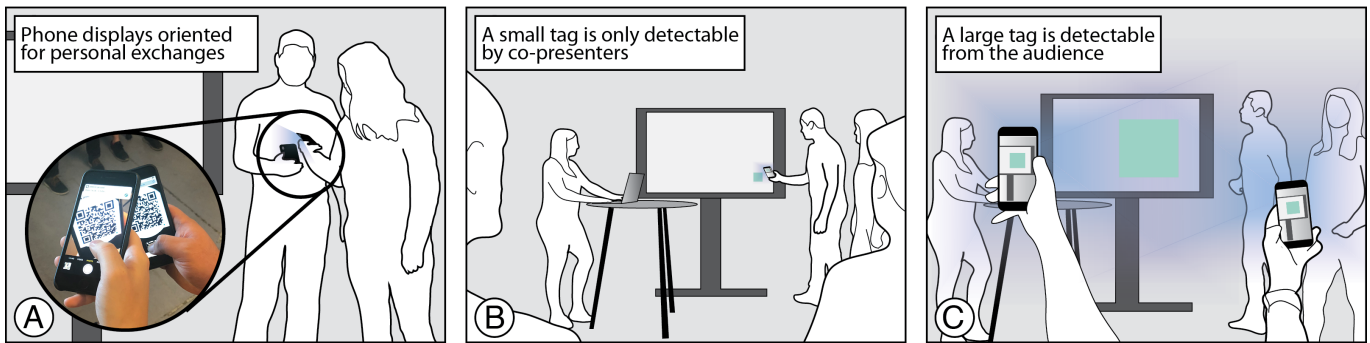


Figure 8. Show-to-Share enables adjusting co-located access to control by manipulating *size* and *orientation* of QR tags via different display properties.



Figure 9. Show-to-Share on fixed and mobile displays. A: A laptop client can scale tag size up and down on a large display. B: A phone client can swipe between slides. C: A phone client displays a tag via a share button.

parts within the Mark Weiser publication. In juxtaposition to the affinity diagram, Emma finds the sticker associated with the publication link and points her device camera at it to get access to the publication. She also accesses a video associated with another paper (Figure 6B).

Later, they are sitting around the table, and Bob wants to edit a collage that Alice created for their next presentation. Alice has made links to relevant files available to her group in a public folder, accessible through a sticker on the back of her laptop. She is seated on the other side of the table face-to-face with Bob, with her laptop facing away from Bob. Bob scans the back of her laptop (Figure 6A) and is able to download this file from Alice's public folder. Alice notices this action – because the action of pointing with a camera is explicit and visible to others – and Bob explains why he needs the collage file. Alice is already currently editing the file, and they reorganize around the table to work together on it.

Stick-to-Share allows for configuration of persistent access to digital resources by flexibly "*attaching stickers*" (i.e., printed paper) to devices, things or places. Significant to a system like Stick-to-Share, which is purely based on mobile artifacts (paper and smartphones), is the span of proxemic relations that may emerge from its interaction style (**Interpersonal Flexibility**): e.g., scanning the back of another person's laptop embodies a *personal* one-to-one relation between two people (see Figure 6A), whereas a paper pinned to the whiteboard in the group area provides a *semi-public* access point allowing for sustained access to the group of people or visitors to the space. This allows collaborating actors to make socially meaningful content associations and make digital content accessible in contextually relevant ways, similar to interactions with RFID tags [58] or beacons [50].

Furthermore, Stick-to-Share supports the ability to increase possibilities for accessing the same resource in multiple ways by printing the same image target ('access point') multiple times and placing it in multiple contexts (**Multiple Alternatives**). As demonstrated in the observations, paper artifacts can easily become part of semifixed and fixed features – such as sticking to whiteboards, cork boards, or walls using magnets, pins or tape – in ways that are meaningful to a group of people (**Fixed and Semifixed Features**). However, they may also be attached to other mobile artifacts, becoming a more dynamic feature of space. For instance, the explicit gesture of pointing a mobile device camera at a sticker (an action visible to co-located others) has a different social meaning when attached to the back of a laptop, in that it discloses a person's intent of accessing an other person's digital resource.

SHOW-TO-SHARE

With Show-to-Share (see Figure 8), we focus on how the architectural layout (including displays) in a presentation situation can provide multiple proxemic opportunities for action.

Prototype

Show-to-Share is a web-based presentation tool that generates QR codes via a REST API ¹. Most mobile phones have built-in or downloadable apps for QR scanning. The laptop version of the web app supports QR scanning via the front camera, allowing mobile phones to share a new slide deck to it for presentation by showing a code from phone to laptop. The QR code contains an access token that allows for different levels of control, ranging from posting a slide-related question with temporary slide controls granted (audience) to having full control of the slides (presenter). The system makes access to control flexible by providing multiple interaction possibilities for sharing. On laptops connected to large displays, the QR code can be scaled up and down to *change the detection range* (see Figure 9A). Presenters can further decide to show the QR code on different devices (e.g., large display, laptop or smartphone as in Figure 9B-C), consequently requiring scanners to be at a certain *distance* and *orientation* to the display.

Empirical: Lack of Manipulation Alternatives

The design of Show-to-Share is inspired by observations from a presentation session that illustrate how personal devices and fixed (shared display) and semifixed (table and chairs) features

¹QR code generator API <http://goqr.me/> (Accessed 03-01-2019)

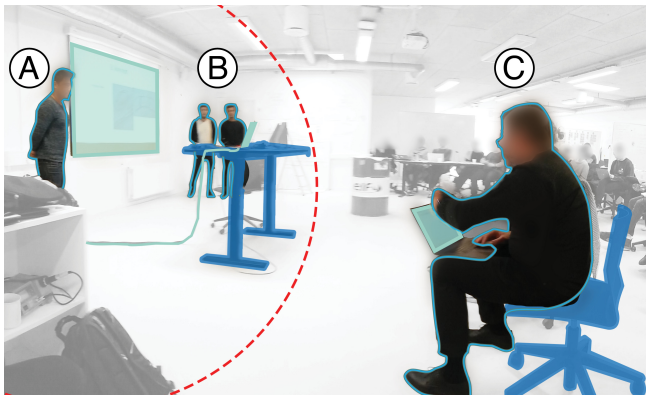


Figure 10. Two zones in group presentations. A-B: In the presentation zone, A is the presenter with control access, and B are two co-presenters who can point at the shared fixed display. C: In the audience zone, people sit on chairs and view the shared display from a distance.

of space collectively shape opportunities for action in a presentation situation for the students and teachers involved. During the session, student groups switched between presenting their projects and getting feedback from the audience (teachers and other students). A slide deck was pre-configured to contain slides from all groups, in order to present from a single laptop cabled to a large display and avoid tedious switching of display cables between laptops when new groups had to present. Figure 10 shows how the connected laptop is placed on a table near the large fixed display and people sit on chairs in the audience. This arrangement separates presenters and audience in zones during presentations, where the large display is viewed from a distance by the audience and controlled from the laptop by only one of the presenters. It has previously been argued by Chattopadhyay et al. that participation during such presentations – e.g., walking over to a laptop to temporarily take control for navigating and pointing at slides – is socially burdensome [18]. In line with this, we found that during presentations, only the one group member nearest the laptop would remain in control of slides (Figure 10A). Other presenters (Figure 10B) would verbally instruct that person to navigate and point on slides. The same dynamics occurred during feedback sessions: when audience members referred to slides via verbal instructions from a distance (see Figure 10C).

Design Rationale: Multiple Alternatives for Showing Tags

Extending the idea of Office Social [17], we focused on designing for multiple opportunities of distributing wireless control by exploiting the spatial arrangement of people, technologies and features of the environment (as annotated in Figure 10). The following scenario envisions how Show-to-Share enables multiple proxemic ways of distributing wireless control:

Alice, Bob, and Emma enter the stage to present their project ideas. The laptop that is hooked to the large display is resting at the table on one side. Alice shares a slide deck to the laptop via her mobile phone displaying a QR code to the laptop front camera. She then shares access to controls with Bob's mobile phone by presenting a small code on the large display that he scans and Emma subsequently scans Bob's phone display where Bob shows the code (Figure 8A). During the presentation,

each presenter can move freely around the slides with wireless access to controls. Bob points at something on slide 10 and then flicks (via the phone) through to slide 11 to point at a figure, making a verbal connection between these two entities of the slide deck.

The presentation ends on a Q&A slide. Alice shares a QR code on the display, scaling it up to a size that anyone in the audience can detect with their phones. The access token of this code contains privileges for posting questions on the Q&A slide. The teacher Peter and others in the audience can scan the code (see Figure 8C). After scanning, they can fill in questions and comments about the presentation. The presenters moderate the Q&A and ask Peter to make his comment. Peter uses the wireless controls to jump straight to slide 11 and uses the remote pointer via touch on his mobile phone to direct the attention to a particular figure on the slide while remaining seated. He flicks back to the previous slide to provide more context to his question.

Show-to-Share supports multiple manipulations to achieve the same social outcome (**Multiple Alternatives**): a presenter can, for instance, share with a co-presenter either by 'showing' a small tag on a large display or by 'showing' a tag on a (small) mobile display. Because of the different features of the display form factors (size and mobility), these manipulations have different proxemic consequences. For instance, sharing via a large display supports one-to-many relations with a scaled-up tag (see Figure 8C) and one-to-few relations with a scaled-down tag (see Figure 8B), and *one-to-one* relations are supported via mobile devices (see Figure 8A). A mobile phone display enables a presenter to establish a *personal sharing zone* with a co-presenter, configured by characteristics of the mobile phone; its *display size* (small) and *mobility* for re-orienting the display allow for fine-grained control of which person to invite for scanning a tag shown on it. This demonstrates the spectrum of multiple ways that co-presenters can share controls with each other and the audience.

Figure 10 illustrates the common proxemic configuration of presentations, separated in two zones; (1) a presenter zone where presenters are standing near the display, one person nearest laptop controls, and (2) an audience zone where members are sitting on chairs at a distance to have the full display in view. This configuration is a fixed feature of the space during the entirety of the presentation, facilitated by a fixed display, a table for the presentation device, and chairs for audience members. Show-to-Share augments this configuration of **Fixed and Semifixed Features** by allowing for presenters to shape how control access is made available to others through showing/hiding, resizing or reorienting QR tags on displays to configure the sharing relation between people and displays.

The explicit scanning of a tag within line-of-sight of the display and within range of the detection threshold is a purposeful constraint, allowing the presenter currently sharing to remain in control of *who* gets access *when*. However, the interactions of "*showing displays to others*" provides opportunities to manipulate size and orientation of QR tags, making the system adaptable to different architectural arrangements of

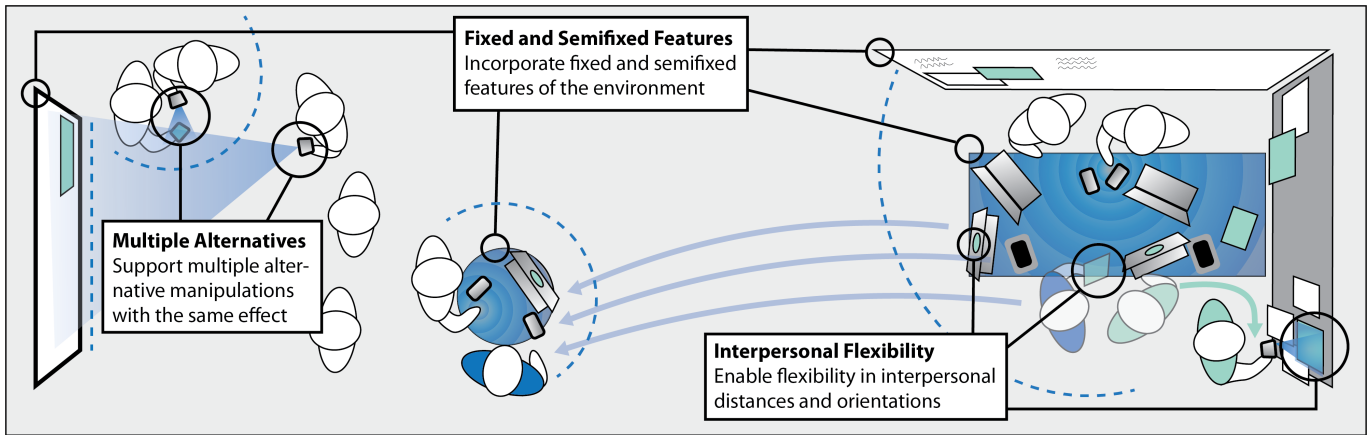


Figure 11. Proxemics Beyond Proximity: People exploit artifacts in the environment – such as tables, paper artifacts, and mobile and fixed displays – to flexibly enact proxemic relations for ad hoc sharing. We suggest three design sensitivities to augment these practices with cross-device interactions.

displays and people (**Interpersonal Flexibility**). For instance, showing a large QR tags on the display creates a “broadcasting” zone with a one-to-many sharing relation, however, it also supports sharing controls in a one-to-few relation with nearby co-presenters by scaling down the tag. Comparing to Proxemic Presenter [24], we can see that the way in which sensing is applied to interaction has different proxemic consequences. Proxemic Presenter allows for implicitly unlocking slide controls when a presenter orients towards the display within a certain distance threshold. However, by making distance thresholds flexible, as illustrated with Show-to-Share, we can make the same detection mechanism adaptable to different social purposes and physical environments.

DISCUSSION

In the following, we discuss the contributions and delimitation of the design sensitivities presented in this paper, including how they point to future directions for cross-device systems.

A Design Lens for Proxemics Beyond Proximity

Our work has started to unpack an approach to cross-device interaction that considers *proxemics beyond proximity* (see Figure 11). The goal has not been to make general judgments about certain cross-device sensing systems (such as whether mobile or stationary sensors are generally better or worse). We neither suggest that our prototype systems are optimal solutions for all sharing practices, and future work is needed to validate the design sensitivities through evaluation of prototypes with users. For instance, slamming tables when sharing is certainly not appropriate in more serious social contexts. However, the prototypes serve as exemplars highlighting less articulated opportunities for designing flexible cross-device systems. Based on our research approach – embracing the complexities of real-world conditions from field observations – we contribute to existing research on cross-device systems (often studied in the lab, e.g., [52, 41]) by proposing design sensitivities, grounded in proxemics theory and empirical work.

Furthermore, framing our design exploration by observations from a specific real-world practice has its limitations: design rationales are limited to the characteristics of the practice and furnished environment that we observed. For instance, the socio-spatial context was specifically relevant for considering

flexibility in interpersonal space (as opposed to high security constraints, for instance). Hence, rather than considering our design sensitivities as an exhaustive list, we argue that they serve as starting points for operationalizing proxemics beyond proximity detection, outlining a research direction on designing cross-device interactions for flexible social interaction.

Adopting Sensitivity to Fixed and Semifixed Features

We have demonstrated through prototypes how interactions with mobile built-in sensors (accelerometers, gyroscopes and cameras) can incorporate features of the environment as part of the cross-device interaction, e.g., allowing tables, walls, boards and fixed displays to have agency in the interaction (**Fixed and Semifixed Features**). Other researchers have also drawn attention to such concerns of proxemics beyond proximity, operationalizing relationships between interpersonal and architectural space for design [16, 29, 31, 40, 21, 26], and our examples build on this work. For instance, our work is inspired by Buxton’s Space-Function Integration [16], where space design (e.g., locations of fixed display devices) is considered to have social meaning. Furthermore, a few cases specifically engage with the proxemics literature [6, 40, 26]. For instance, Ballendat et al. [6] and Marquardt et al. [40] discuss how Proxemic Interactions may consider fixed and semifixed features as mediators of interaction, such as allowing the use of a (semifixed) couch to become a signifier of intent in the Proxemic Media Player. They suggest that the position of semifixed features needs to be continually tracked. The focus here is on how such features can mediate implicit human-computer interaction through proximity sensing.

However, in adopting a sensitivity to **Fixed and Semifixed Features**, we suggest to consider the *interplay* between social interaction, cross-device systems and their environment. Our prototypes demonstrate how fixed and semifixed features can become resources for mediating human-human interaction through cross-device interaction. They are only examples of incorporating features, and the idea may be applied in principle to any sensor when considering which proxemic relations to enable. For instance, RF-based techniques [33, 56, 38, 48] (e.g., WiFi, Bluetooth) exploit a signal range that goes beyond walls. In contrast, microphone-based techniques [3, 32] detect

signals from devices *within* boundaries of walls (dependent on how loud the sound signal is). While not explicitly tracking proximity, techniques using mobile cameras [5, 11] exploit line-of-sight between devices, and techniques based on device motion [42] and orientation [27, 34] exploit synchronous gestures by people sharing the same space.

Adopting Sensitivity to Interpersonal Flexibility

The fundamental ideas of **Interpersonal Flexibility** build on prior HCI research. Luff et al. [37] studied how placement and manipulation of paper in relation to the physical work space serve to manage the dynamics of collaboration. They identified key characteristics of paper artifacts such as *micro-mobility* (the fine-grained orientation and re-positioning of artifacts to manage how they are viewable by others) and *local mobility* (the movement of artifacts through different spaces in the local vicinity), and these have also informed design of cross-device environments [9, 8, 41]. The design sensitivity is further inspired by Krogh et al.'s sensitizing concept of Proxemic Malleability, defined as the ability of an interactive system to support a range of socio-spatial relations [35].

We extend this research with concrete design rationales for cross-device interaction. In contrast to cross-device interactions that detect human-human proximity (e.g., [41]), our examples of **Interpersonal Flexibility** allow for re-configuration of the relations between people and their environment through manipulation of the cross-device system. For instance, the Show-to-Share idea of manipulating the *distance* with which a camera can detect a tag invites for further investigation into flexible detection mechanisms with other sensors. For microphone-based techniques (e.g., Chirp [3]), the volume of a signal affects the range with which a microphone can pick it up. In this way, adjusting volume is effectively fine-tuning the bounds of the sensing area for sharing – and artifacts such as megaphones can make these bounds flexible.

Adopting Sensitivity to Multiple Alternatives

Finally, similar arguments to the idea of **Multiple Alternatives** have been made about the ability to remote control in collaboration practices, e.g., via touchless interaction (e.g., [44]) and cross-device interaction (e.g., [35, 17]), showing that remote control enables more flexibility of action in collaboration. By providing multiple proxemic ways of gesturing around a shared display (next to it or from a distance), a system can enable multiple alternative actions for achieving the effect of communicating around displayed content.

We complement these suggestions with design proposals of cross-device interactions that enable multiple interaction possibilities for achieving the same effect. For instance, Show-to-Share allows for sharing both via showing a QR tag on the mobile phone, the laptop screen or on a large display (scaled up or down), all possibly leading to the same effect, but with different proxemic consequences (i.e., different conditions for how people can move in relation to each other and the QR tag). While Show-to-Share conveys this sensitivity through the manipulation of a camera-to-tag relation, the sensitivity invites for further ideas, such as sensor fusion. Deploying multiple sensors simultaneously can enable users to switch

between distinct sensing properties for configuring a sharing relation to others, e.g., switching between RF-based (from a distance) and NFC-based (close proximity) sharing.

Flexibility is Not Always Better

Our research builds on Krogh et al.'s work to advance *socio-spatial literacy* [35], meaning to *articulate* system properties in terms of how they frame the organization of socio-spatial behaviour. They argue that systems supporting high Proxemic Malleability are neither good nor bad in general, but rather may be good for some social situations and bad for others.

Motivated by our field study of collaboration (relying on mobility and flexibility), our prototypes specifically explore how cross-device interactions can be designed to be adaptable to different socio-spatial configurations. Hence, the actions enabled by our prototypes have certain characteristics that are meaningful to such flexible practices. However, *limited* flexibility may be more desirable in other situations. For instance, the tradeoff is clear when comparing the inherent *range* properties of RF-based (e.g., AirDrop [1]) and NFC-based (e.g., Android Beam [2]) techniques: AirDrop enables people to flexibly arrange for sharing from one to many devices enabling sharing from anywhere within a long range (> 10 m), while Beam requires devices to nearly touch (< 10 cm) – a physical gesture that embodies trust between users.

Furthermore, our choice of *mobile* sensing infrastructure is motivated by the importance of *mobility* in the studied practice, where fixed sensing equipment was less desirable. However, in some practices, it might be desirable to limit the mobility. For instance, a fixed tracking area (e.g., in HuddleLamp [52] and Collaborative Workplace Table [48]) can be used as an explicit resource for configuring interpersonal relations: it supports making a system for cross-device sharing a fixed feature of space, where the act of sharing is bounded to one particular table surface. This may be desirable for enforcing high security requirements on certain exchanges.

CONCLUSION

While proximity detection enables ad hoc cross-device interaction, it also constrains flexibility in social interaction. Through prototyping, we explored how cross-device interactions can enable flexible proxemic relations for ad hoc sharing. To this end, we propose three design sensitivities for supporting flexible social interaction through cross-device interaction: (1) *Incorporating fixed and semifixed features of the environment to constrain and enable action during collaboration*, (2) *Enabling flexibility in interpersonal distance and orientation during sensor-based interaction*, and (3) *Supporting multiple alternative manipulation opportunities to achieve the same effect*. Informed by proxemics analysis of sharing practices in the wild, three prototypes are developed as demonstrators of how designers may adopt these sensitivities. With this work, we hope to inspire others to consider how properties of cross-device systems combine with fixed and semifixed features of the environment to enable flexible social interaction.

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