Creating Your Bubble: Personal Space On and Around Large Public Displays

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ABSTRACT
We describe an empirical study that explores how users establish and use personal space around large public displays (LPDs). Our study complements field studies in this space by more fully characterizing interpersonal distances based on coupling and confirms the use of on-screen territories on vertical displays. Finally, we discuss implications for future research: limitations of proxemics and territoriality, how user range can augment existing theory, and the influence of display size on personal space.

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Proxemics; Territoriality; Coupling; Large Public Displays

INTRODUCTION
As large displays have become increasingly affordable, they have also become feasible platforms for transient computational tasks in public space. Following the development of initial concepts for large scale, public displays [27, 23, 8], recent work has explored their use as information kiosks [24], in settings such as libraries and museums [11], semi-public office spaces [12, 8], and personal and private interactions in settings such as cinema ATMs and photo kiosks [1, 25]. These interfaces provide an opportunity to redefine how we support lightweight and transient tasks such as wayfinding, information search, and entertainment.

While display hardware for these applications has become readily available, the required tools to build interactive experiences has lagged. Interaction techniques such as Rotate and Translate [16] and Pick-N-Drop [21] provide rudimentary means of interacting with on-screen data, but lack awareness of users' social and cultural contexts. Recent work has developed descriptive theories such as proxemics [2, 6] and territoriality [25] to facilitate the use of individuals' positions to detect social relationships between nearby users, often leveraging low-cost and easily deployed sensors such as Microsoft's Kinect™. While the importance of these factors have been motivated by many studies in the field [3, 5, 20, 22, 30], guidance for how these relationships should translate into practical design considerations is still lacking. That is, how do one's surroundings and task influence their 'personal bubble' when approaching a public display?

We conducted an empirical study that explores how individuals approach, define, and use personal space on large public displays (LPDs). The study complements existing field studies, characterizes interpersonal distances in front of a public display across a range of degrees of coupling, and validates the use of territoriality on wall displays in the digital domain. Based on our results, we discuss opportunities for interaction design on large public displays as users approach and define personal space, and in supporting coupled work.

INTERACTIONS AROUND LARGE TOUCH DISPLAYS
Hall [10] coined the term proxemics when studying the role of interpersonal distances in human interactions, and defined zones of interaction ranging from intimate (less than 0.5m), to personal (0.5m to 1.2m), social (1.2m to 3.6m), and public (3.6m to 8m). As inexpensive, compact, and easily deployable body-sensing technologies have become available, these zones of interaction have been employed to explore proxemics as an input modality [27] and in developing frameworks for their use in LPDs [7, 17].

Research suggests that individuals working closely together, or more tightly coupled, tend to stay closer together [26], for example within Hall's 'personal' distance. By maintaining physical proximity, users are able to better maintain awareness of one another's actions, and more easily communicate as they complete shared tasks. However, these behaviours have largely been observed in private or semi-private settings such as offices or laboratories, and often around a shared tabletop [26]. To address this lack of field research, a number of researchers have deployed LPDs in public [3, 5, 20, 22, 30]. This research has explored how to design for multi-user interaction for indoor installations [22], how pedestrian traffic is shaped by the introduction of LPDs to public spaces [30], how displays should respond to approaching users [15], and how on-screen content can be used to manipulate the position of users in-front of the display [3]. However, little research

Figure 1: a) Participants in front of a 4 × 1.2m display. b and c) Video recorded via cameras above the display.

has focused on users engaged in transient, touch interaction with deployed systems.

Notably, Peltonen et al. [20] observed interaction with CityWall, a photo-browsing application installed in a shop window over an eight day period, and through a mixed-methods analysis describe aspects of interaction such as turn-taking, expressive on-screen gestures, and concluding actions. During their deployment Peltonen et al. observed nearly 1200 people interact with CityWall in over 500 sessions, in which a majority of interactions (72%) involved pairs of individuals. While this large-scale deployment provides data on how people initiate, negotiate, and end interactions with a large installation it is limited in two significant ways. First, the display was only 2.5m wide and was not equipped with proxemic sensors to measure users' positions relative to the display, meaning that multiple users are necessarily within one another's 'personal' space. Second, the photo browsing task supported by the display did not enable the researchers to investigate coupling. We address these limitations through experimental control over the task performed by users, and the use of body-tracking cameras to measure interpersonal distances.

STUDY: COUPLING AND INTERPERSONAL DISTANCE

In order to explore how users define interpersonal and on-screen workspaces on LPDs, we conducted a controlled study. We intentionally focused on interactions between pairs around the LPD, as these interactions accounted for nearly 3/4 of observed sessions in previous field studies [20].

Participants

20 STEM students (11 men and 9 women) between the ages of 19 and 42 ($\bar{x} = 25$) were recruited for the study and randomly paired with one other participant.

Experimental Setup

Participants completed trials on a 170" display measuring 4.1m × 1.2m. The display was composed of 8 × 46" display panels arranged in a 4 × 2 grid, for a total resolution of 7680 × 2160 pixels (16MP at 47 PPI). The display supported up to 32 simultaneous touch points via a custom-built PQ Labs infrared touch frame (Figure 1a). Touch events were captured via the Simple Multi-Touch Toolkit [4, 19].

Experimental Task and Design

The jigsaw puzzle task was chosen as representative of transient tasks wherein users approach a display and quickly perform a series of short interactions, such as searching a kiosk directory or photo album, or playing a casual game. In each trial, two participants were each asked to complete a jigsaw puzzle consisting of 25 pieces (100 × 100 pixels each). For each puzzle, participants were separately asked to select an initial placement of a 5 × 5 grid of shuffled pieces. Once placed, participants dragged individual jigsaw pieces using one-finger translation. When pieces were aligned with their neighbours, they would 'snap' together to form a larger piece that could in turn be dragged around the display. Trials were considered complete once both participants had combined their respective pieces into a single image.

As in [1], we used a within-subjects design with one independent variable: Degree of Collaboration (DoC), which varied the degree to which participants were required to collaborate with their randomly assigned partner. Five levels of DoC were used, ranging from least to most collaborative:

- SIMPLE: Two different puzzles, consisting of 25 pieces each, are placed in front of participants. This level of DoC forms a non-collaborative baseline.
- MIXED-5: Pieces from each participant's puzzle are mixed together. 5 pieces from each puzzle are swapped.
- MIXED-10: Pieces from each participant's puzzle are mixed together. 10 pieces from each puzzle are swapped.
- DUPLICATE: Participants solve copies of the same puzzle, and 10 pieces from each puzzle are swapped.
- SHARED: One large, 50-piece puzzle is completed collaboratively by both participants.

Participants were not informed of the DoC conditions or that that they may need to exchange pieces prior to completing the trials. The order of presentation of DoC conditions was randomized using a partial latin square design.

Procedure

Upon arriving, participants completed an informed consent form and brief demographic questionnaire. They were then introduced to their assigned partner and provided an opportunity to practice placing and solving a puzzle on the display and to ask any questions before starting the experimental trials. This practice session lasted approximately 5 minutes.

Participants then performed one experimental trial for each level of DoC, for a total of 5 trials, with each puzzle taking approximately 5 minutes to complete. During each trial, participants were first asked to select an initial placement for their 5 × 5 grid of jigsaw pieces. After placement, both participants manipulated pieces on the display until both puzzles were solved. After the 5 trials were complete, participants were thanked for their time and paid $5. Each session lasted approximately 30 minutes.

Data Collection and Analysis

The following data were logged in every trial: the time taken to complete each pair of puzzles, the initial placement of personal workspaces, and participant touch interactions with puzzle pieces. We analyzed interaction data to determine distances between the placement of personal workspaces and used it to generate heat maps of participant interactions. We recorded the body position of participants during trials through naïve blob detection using four PSEye cameras with custom wide-angle lenses mounted directly above the large display (Figure 1 B and C). This data was used to measure intra-body distance between participants, defined as the distance between the centre position of each participant. To analyze collected data, we performed Repeated Measures Analysis of Variance (RM-ANOVA) tests, with $\alpha = 0.05$.

Results

We now present results relating to DoC's impact on the difficulty of individual jigsaw puzzles, the degree to which collaboration was required, and participant's on-screen and interpersonal space.

Trial Time and Effort

Trials lasted 400.4s on average ($\sigma = 40.26$). Our analysis revealed a main effect for Degree of Collaboration (DoC) ($F_{4,28} = 5.862, p = 0.001, \eta_p^2 = 0.456$) where SIMPLE puzzle trials took less time to complete ($\bar{x} = 297s, \sigma = 42$) than the DUPLICATE and SHARED puzzle trials ($\bar{x} = 578s, \sigma = 72, p = 0.017$) and ($\bar{x} = 440s, \sigma = 40, p = 0.57$) respectively. No other pairwise differences were found.

On-Screen Workspaces

We first analyzed the use of space for SIMPLE trials. In these conditions, participants on average used a workspace 114 cm ($\sigma = 36cm$) wide × 76cm ($\sigma = 14cm$) high to solve their jigsaw puzzles. In SHARED trials, pairs used a workspace 211 cm ($\sigma = 46cm$) wide × 80cm ($\sigma = 14cm$) high on average. Due to experimental control over the placement of jigsaw pieces in the other DoC conditions, no direct comparisons were made for these measures.

Participants worked within an average screen space 206cm wide × 76cm ($\sigma = 104cm \times \sigma = 3cm$) high and on-screen materials were spaced an average of 106cm apart ($\sigma = 13cm$). Our analyses revealed no main effect on workspace spacing for DoC ($F_{3,21} = 0.736, p = 0.542, \eta_p^2 = 0.095$).

Body Position

Participants stood 158cm apart ($\sigma = 20cm$) on average. Our analyses revealed a main effect for DoC ($F_{4,28} = 8.676, p < 0.001, \eta_p^2 = 0.553$). As expected, participants completing a SHARED puzzle ($\bar{x} = 94cm, \sigma = 8cm$) stood closer to each other than those in the SIMPLE condition ($\bar{x} = 1.76m, \sigma = 0.20m$). Our analysis revealed no other differences between DoC conditions (Figure 2a).

Our analysis of individuals' activity in front of the display also revealed a main effect for DoC ($F_{4,60} = 4.335, p < 0.004, \eta_p^2 = 0.225$). Participants had a larger range in front of the display in the MIXED-10 condition ($\bar{x} = 198cm, \sigma = 20cm$) than in the SIMPLE and SHARED puzzle conditions ($\bar{x} = 140cm, \sigma = 12cm, p = 0.017$), however no other pairwise comparisons were significant (Figure 2b). Example heatmap data is illustrated in Figure 3.

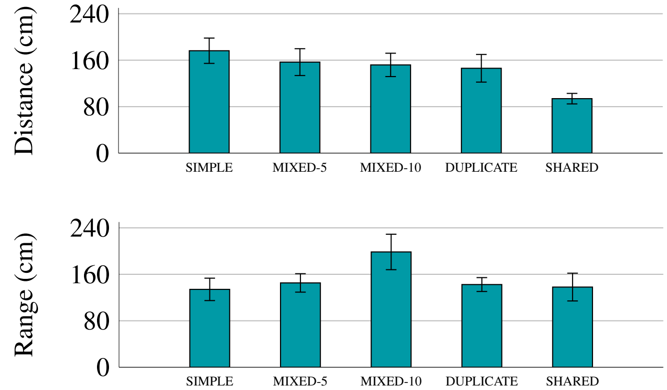

Figure 2: a) Participants completing a SHARED puzzle stood closer together than in the SIMPLE condition. b) Participants had a larger range in the MIXED-10 condition than in the SIMPLE and SHARED conditions. Error bars show standard error.

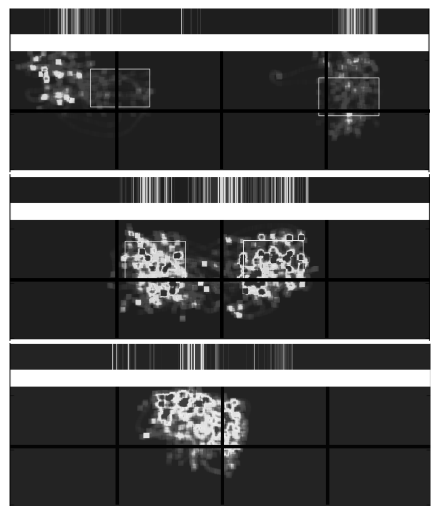

Figure 3: Heatmaps for 3 DoC conditions: SIMPLE (top), MIXED-10 (middle), and SHARED (bottom). For each map, body position is displayed above touch events.

Discussion

Our analysis reveals significant differences between extremes in DoC for trial time and inter-body distances, which is consistent with the literature [26]. This finding suggests that the experimental control was successful in simulating varying degrees of coupling during the transient puzzle solving task. We now discuss how participants defined personal space and interpersonal distances as they progressed through the task.

Defining Personal Space

Participants each worked with 25 small, independent jigsaw pieces that were freely positioned on the large display. We found that individuals manipulated these pieces within an on-screen area of on average 1.14 × 0.76m ($\sigma = 0.36 \times 0.14m$). Pairs completing a shared puzzle made up of 50 pieces worked within a personal space measuring on average 2.11 × 0.81m ($\sigma = 0.46 \times 0.14m$), and we found no differences in the distances based on DoC. As in [1], participants moved unused pieces into storage areas, predominantly to the side of their working space. This behaviour is reflected in our measures since they *include* storage space, and were derived from the spread of all pieces belonging to any one puzzle. Field notes, cross referenced with post hoc analyses of interaction data visualized as heatmaps corroborates the use of territories on the large display. Thus, we confirm Azad et al.'s [1]observations regarding the use of on-screen territories on LPDs.

Movement
Our body tracking data revealed that, on average, participants stood 158cm apart ($\sigma = 0.2m$) while completing the jigsaw task in our study, contrasting Azad et al.'s average of 61cm. Azad et al.'s participants established themselves within a 'personal' distance of one another, whereas our participants worked within a 'social' distance. These differences may be a result of the display sizes used between the two studies: our display measured 4×1.2m, whereas Azad et al.'s display measured 3×2m. Since our display was wider, it may have afforded a greater interpersonal distance.

Our analysis of interpersonal distance revealed that pairs completing SHARED puzzles stood closer together than other pairs ($\eta_p^2 = 0.553$). We found no differences between the other 4 levels of DoC. When considered in the context of related literature [13, 28, 29], our results further validate that tightly coupled work correlates with a closer proximity between collaborators, but do not provide sufficient statistical power to differentiate between loosely- and un-coupled pairs.

IMPLICATIONS FOR FUTURE RESEARCH
There remain a number of challenges in understanding how to support users as they approach and interact with an LPD. Our results characterize personal space and movement needs, and suggest a need for future research in three areas:

Limitations of Proxemics and Territoriality
While interpersonal zones are easily measured using body-tracking cameras, there is a lack of guidance surrounding how LPDs should interpret this input. For example, when can individuals be considered to be coupled? And can proxemic interfaces identify and support collaborative activity [9]? Our results suggest limitations of proxemics and territoriality theories in supporting these use cases. Participants approached the display in a similar manner regardless of their degree of coupling. Upon establishing personal space, however, we found that users often, and fluidly, reorganized on-screen artefacts into personal and storage territories and stepped outside of that space to ask neighbours for help. This process arose organically through interactions with the task materials such as handoffs/deposits [9] and sorting and prioritization [29] (Figure 1c). As territories evolve on-screen, they are often passed from one user to another during tightly- or loosely-coupled work, and one user's storage may become another's active workspace. In these settings, we found that measures such as inter-personal distance could distinguish between SIMPLE and SHARED workspaces, but not intermediate levels of coupling.

Augmenting Proxemics and Territoriality
Interestingly, our results suggest that a user's *range* may prove useful in identifying the degree to which they are collaborating with others nearby. This finding fills a gap in the literature where research has identified correlations between proximity and degree of coupling [26], but has also noted that pairs can work effectively at a distance in front of large displays [14]. Further, these results suggest a need to augment proxemic and territoriality theories for use in LPDs. For example, while proxemics can suggest what users are doing *right now* by identifying nearby items or individuals [18], it does not provide information about relationships between individuals or devices over time. Range of motion may be one way of augmenting proxemic interactions to address this need, particularly when pairs are loosely-coupled.

More generally, we suggest the potential of 2nd order interfaces in supporting interactions on LPDs. We anticipate that as a deeper understanding of proxemic and territorial relationships is developed, models that take into account multiple inputs will evolve. For example, interaction models could identify user intentions as they move towards/away from storage zones; taking into account both a user's position, and the contextual meaning of the space that they occupy. Current tools and theory provide a foundation on which these interfaces can be developed, but research is needed to identify how to best identify and track interpersonal relationships over time.

The Influence of Display Size on Personal Space
Finally, research has often focused on large displays that fail to extend beyond Hall's 'social' region of 1.2 – 3.6m [3, 5, 20, 30]. However, LPDs that extend to 'public' space (i.e. > 8m) are now feasible [22], and it is unclear how user interfaces should evolve to fill the needs of users working on such a large, shared surface. Our research complements research that has explored pedestrian traffic around LPDs [30], how to respond to approaching users [15], and how to manipulate the position of users in-front of the display [3]. Our results suggest that results may vary on larger displays, such as our observed increase in personal space, and demonstrates a need to replicate past results with larger displays.

CONCLUSION
Our work was motivated by a need for stronger guidance in developing LPDs. We conducted a laboratory study to carefully measure interactions in front of a large display, and triangulate observations with existing field work (e.g. [1, 20]). Our study validates the use of territoriality on a vertical interactive surface, but indicates a need for further research in key areas: the limitations of proxemics and territorially for LPD design, exploring movement in augmenting distance as an input modality for LPD interfaces, and raise the need to recognize display size's influence on personal space.

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