Proximity Table: Exploring Tabletop Interfaces that Respond to Body Position and Motion

by

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Dedication

Words cannot express the gratitude I feel for
the nurturing and support that my parents
have provided me in this life.
It is my sincere hope that they are as proud of
their son as their son is of them

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Abstract

This thesis presents the ProximityTable framework, an interactive tabletop system that uses a top-down tracker to track users around the display. Based on this tracking data it generates a number of proxemics events that can be used by developers to generate application-based responses. The main goal of this thesis is to apply Hall's proxemics theory to the design of interactive tabletops in order to support the work of multiple groups around a single interactive tabletop display. A set of proxemics-based interactions were designed using the core features of ProximityTable, and evaluated in three focus group sessions. From our evaluation, we found that the majority of our participants also agreed that adapting the workspace according to group size allows for better interaction with the display, where users can directly interact with the display or have a better view of the contents in the workspace. Even when the majority of our participants chose to work on joined workspaces, there were some instances where they split the workspace in the middle of the task to complete tasks in parallel. We also found that users preferred to have a balance between user and system control, which will allow them to have manual control of the responses to proxemics events that is supported by system's detection.

LIST OF ABBREVIATIONS USED

NUIs	Natural User Interfaces
IR	Infrared
NFC	Near field communication
DT-DT	Dal Top-Down Tracker
OSC	Open Sound Control
UI	User interface
SDK	software development kit
WPF	Windows Presentation Foundation

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Special thanks go to my family, especially my brothers and sisters, whom I have missed these many years, being away from home.

Finally, I would like to express my sincere love and gratitude to my parents. I owe them more than anyone could possibly imagine, notwithstanding my academic achievements. I thank them for their love and infinite care, which has made the person I am today.

Chapter 1: Introduction

We are at the beginning of a new generation of user interfaces that is known as Natural User Interfaces (NUIs). There are different forms of NUI including in-air gesture interfaces and touch gesture interfaces. Touch interfaces might be the most common type of NUI due to the use of such technology with the devices that people use in their daily life such as touch screen phones (e.g. iPhone) and tablets (e.g. iPad). Such interfaces can be divided into three types in terms of the number of contacts that they can sense a1nd report at the same time. With “single-user manipulation” the system requires only two points of contact in order to sense a gesture language (e.g. to accomplish dragging and zooming). In “single-user gestural”, the gesture requires a small number of points of contact to be performed by the user. Finally, in “multi-user gestural”, multiple users perform multiple touches at the same time; this requires a large number of points of contact [1]. The focus of this research will be on multi-user multi-touch interfaces.

The use of multi-user tabletop interfaces has been increasing across a number of domains, such as “retail, education, and public places” [18]. In many cases, multiple individuals can independently and simultaneously use the table interface (e.g. at museums as discussed by Klinkhammer et al. [2]). In other cases the interface is meant to be used collaboratively (e.g. in the classroom as seen in OurSpace [4]). Still other cases permit a mix of independent and collaborative use (e.g. educational applications such as PiVOT [10]).

To develop a multi-user interface we must understand what types of tasks will be performed using such interfaces, one important aspect of which is task coupling

[1]. There are three levels of task coupling: first, *highly coupled tasks*, where users work together to complete one task. Second, *lightly coupled tasks*, where users work independently to achieve results that are based on the completion of all users' tasks. Third, *uncoupled tasks*, where users work independently on tasks that require no coordination. In similar spirit to these three levels, Tang et al. categorized tabletop tasks into six coupling styles [17]. Four of them can be categorized into the three levels listed earlier. I.e. "Same problem same area" and "One working, another viewing in an engaged manner" belong to highly coupled tasks. "Same problem, different area" is a sub-type of lightly coupled tasks. "Different problem" goes under uncoupled tasks. The other two are "One working, another viewing" and "One working, another disengaged".

For highly coupled tasks usually users work together on a full screen (one territory on all tabletop). In the case of lightly coupled tasks usually there are two territories, a shared region in the center of the table known as the group territory and private areas at the edges for each user, known as personal territories ("Private space") [3]. By contrast, uncoupled tasks required that each user be given a private area to complete their work independently.

While these categories describe many tabletop interaction scenarios well, in practice we can see a mix of highly, lightly and uncoupled tasks as well as observing the interaction (viewing or disengaged) occurring on a single tabletop display. This is seen when more than one group, each with their own workspace, uses a single interactive tabletop. Examples of using a single display by multiple groups include families using a tabletop at a tourist center or a museum (e.g.

Build-a-Tree [26]), groups of elementary school students doing a classroom activity (e.g. Youtopia in [24] and PhysicsBox [25]), and college students completing lab activities in pairs (e.g. GreenTouch [27]). To support such cases, a system that can detect the relation of the user's position to the table and to other users at the table might be beneficial (we call such a system *proxemics-aware*). Therefore, we propose and demonstrate ProximityTable, a system that is able to differentiate between a single user vs. a group and a user vs. a bystander. To the best of our knowledge, no systems have been demonstrated that can identify interested bystanders around the table, or automatically distinguish between group of users vs. independent users. Each of these would be useful in mixed coupling scenarios, by supporting a range of group formation and group division events. For example, when a family member is interacting with the tabletop at a tourist center while the others stand behind him/her and watch, the size of the presented content might be increased in order to allow everyone to have a clear view of the contents. Further, if all family members are interacting with the tabletop independently at the same time, they might decide to group together to share what they have found, at which time a larger workspace could be allocated for them.

ProximityTable considers a mix of highly coupled and uncoupled tasks by allowing two groups work independently in different workspaces. It also consider a mix of highly coupled and lightly coupled with uncoupled tasks; this occurs by allowing one group to have multiple workspaces to complete their task while the other group is working on a single workspace. In addition, ProximityTable recognizes onlookers (viewing or disengaged) and notifies the main user about their presence, which might be useful to increase the size of the workspace.

One of the meanings of space is the "personal space of the organism" [39] defined as "the distance that the organism customarily places between itself and other organism" [39]. Edward Hall expanded this meaning of personal space and introduced proximity theory in his 1965 book "The Hidden Dimension" [5]. Proxemics is defined as how a person perceives and uses the immediate space around him/her. Hall identified four distance zones around each individual: intimate distance, personal distance, social distance, and public distance as shown in Figure 1.

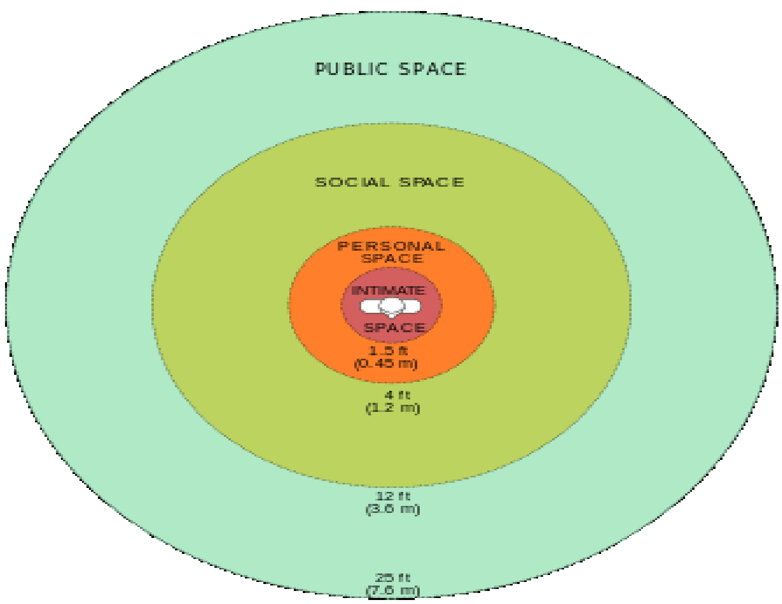

Figure 1: Diagram of Hall's personal reaction bubbles [6]

Hall's theory has been applied by a number of researchers, where researchers detect the relationship between users and the display in order to apply changes to the interface based on users' positions (discussed in Chapter 2). The main goal of the research presented in this thesis is to apply Hall's proxemics theory to the design of interactive tabletops in order to support the work of multiple groups around a single interactive tabletop display. Our work is grounded in proxemics and concerned with individuals' spatial relationship with the tabletop display, but also pays attention to principles underlying group arrangements around (and near) the display.

To do so, we need a system that not only tracks users interacting directly with the table but also individuals who are standing behind him\her. For example, if a new user is trying to look over shoulders of current group members, the system might display something in a different part of the table to capture the attention of the new user and notify him/her that s/he can use that region to interact. Such a system also should be able to differentiate between single users and groups as well as detecting the number of group members. For example, the system might create workspaces for individuals and groups with different sizes according to group sizes. For this purpose ProximityTable was implemented. As with other proxemics-aware interfaces, ProximityTable detects users' indirect behaviors and changes the interface configuration according to these behaviors. Importantly, ProximityTable considers both the individual's spatial relationship to the tabletop display and to other people at and around the table. A set of prototype proxemics-based interactions were designed using the core features of ProximityTable, and evaluated in three focus group sessions. The focus groups also provided an opportunity to explore future application designs using ProximityTable features.

1.1 Contributions:

This research makes the following contributions:

- System contributions:
    1- Extends a unique top-down human activity tracking framework to acquire proxemics data of multiple individuals around an interactive table in order to support collaboration.
    2- Defines an event model for proxemics events relevant to tabletop interaction.
    3- Demonstrates how proxemics events and multi-touch interaction events can be meaningfully combined to support tabletop activities.
- Design explorations:
    1- Implements and evaluates a prototype museum information tabletop application using these new proxemics features.
    2- Validates the use of ProximityTable framework in a museum scenario.

1.2 Structure of the thesis:

This dissertation is divided into eight chapters as follows: chapter 2 discusses the related work including collaboration and tabletop territories, proxemics and interactive displays, as well as existing tracking systems. Chapter 3 states implementation objectives and describe the architecture of the ProximityTable framework including: selected tracking system and why it was chosen, generated proxemics events and how they are generated, and challenges during the implementation phase. Chapter 4 describes the ProximityTable application, including its responses for each proxemics event as well as the interface itself.

Chapter 5 discusses the focus group study design starting with research objectives and the types of tasks employed, a description of participants, and the analysis process. Chapter 6 discusses the results of the user study that is categorized under ProximityTable features. We also present some alternative uses of ProximityTable. Chapter 7 discusses our framework as well as future improvements, and conclude in Chapter 8.

Chapter 2: Literature review

This chapter will discuss related work that includes: territories and collaboration over tabletop interactive displays (section 2.1), proxemics and interactive displays (section 2.2), and group formation around public interactive displays (section 2.3).

2.1 Territories And Collaboration Over Tabletops Interactive Displays:

One of the main purposes of using traditional tables is to perform collaborative work that employs the use of traditional tools (e.g. pen and paper). According to observations of such collaborative work, people partition their workspace into a number of territories. First, personal territories are the immediate areas in front of each person, which are used to perform individual tasks. Second, group territory that is the shared area between all collaborators (in the center of the table), which are used to share or perform collaborative tasks. Third, storage territories, any areas out of other territories that are employed to keep noncurrent used documents [9, 11]. Figure 2 shows an example of this partition.

In the case of digital collaborative tabletops, there are personal territories (or private territories) and group territory (or public territory) [1]. Partitioning approaches used in interactive tabletops are somewhat similar to those seen in traditional tabletop work. A number of partitioning approaches can be seen in tabletop systems: one territory for all users (without any predefined areas) [4, 7,

[1] We do not discuss storage territories in digital tabletop systems in this thesis, as they are less immediately relevant to proxemics-aware tabletops.

8], private and public territories [3, 10, 29], and only private territories [2]. The following subsections discuss each approach in detail.

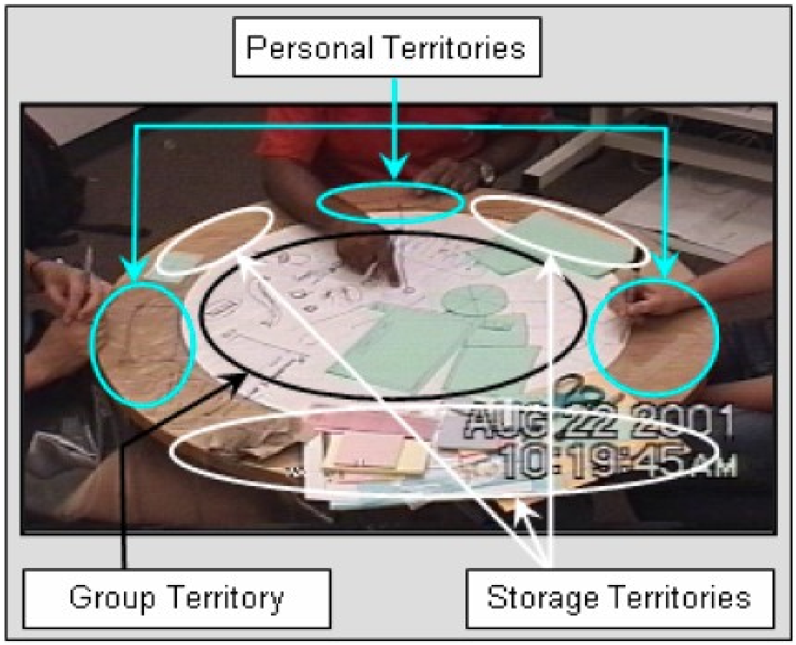

Figure 2: Personal, group, and storage territories [9]

2.1.1 One Territory For All Users (No Predefined Areas):

With this type of interface, there are natural divisions of the display where people agree that the area in front of each user is his/her personal territory. In addition, this type of interface is mostly used for highly coupled tasks where users work together to complete a task. There are a number of systems that have applied this concept. For example, CollabDraw [7] is a one territory system that provides highly coupled interaction techniques or what they call "cooperative gesturing". With this type of interaction technique, the system receives combined gestures by different users as a single one in order to perform tasks such as creating diagrams and simple animation. This system provides a set of 16 gestures, 11 for cooperative gesturing and 5 for single-user.

OurSpace [4] is also a one territory tabletop application where students (from year 3 and 4) work together to arrange their classroom's desks. Its main goal is to understand how child's involvement can be affected by position around the table and touch interaction. This research mainly found that all children used the entire display but at the same time each child become more responsible for his/her personal territory.

SIDES [8] is another one territory tabletop example. It is a four-player collaborative game that aims to support adolescents with Asperger's Syndrome in order to involve them effectively in group work. This game is meant to be used in social group therapy and support group work skills such as "negotiation, turn-taking, active listening, and perspective-taking" [8].

Futura in [33] is a collaborative game that allows users (children and adults) learning planning for the future to meet people's needs without any impact on the environment. In Futura, each player is responsible for his own play but they have to work collaboratively, since individuals' decisions will impact the final results of group's plan, in order to meet future requirements for both people and environment.

2.1.2 Private And Public Territories:

This type of interface is meant to be used by groups of people performing semi-collaborative tasks. These interfaces provide each user with a private area to interact with and public area that all users have access to. RoomPlanner [3] is an example of such an interface where users can work in their private areas and then share their work with the group on a shared region of the table. It provides users with a number of interaction techniques that include multi-finger and whole hand gestures. It also discusses privacy and awareness through a number of interaction techniques.

There is another way of using public and private territories that is applied in PiVOT [10]. Instead of providing private area for each user at the edges of the display, PiVOT provides personal overlay over the public area that can be used to perform individual tasks. In addition, PiVOT uses ARToolKitPlus software in order to track markers worn on users' heads as well as tangible markers. A user can get access to enhanced view by leaning forward, and by placing a tangible marker s/he will access personal overlay and start to explore the content. PiVOT was used as an application for teaching human anatomy, where the shared view shows a 3D model of the human body. The organs that can be explored are shown in the enhanced view and more details about those organs are presented on the personal overlay.

Interface Current in [29] is an interface that consists of two types (stream currant and pool currant) that provide users with a continuing flow of interface's items (e.g. images). Through the use of these types users will be able to create "photo story" by choosing pictures from the collection and place them in the "Story Page". In Interface Currant, private territories are the spaces in front each user in both types, which can be resizable in the case of Stream Currant. Public territories are the "Story Page" and the center of the interface.

Tangible Private Spaces (TaPS) widgets [35] is another way to create a private space that is not only to interact but also to prevent others from seeing the contents in the created private area. These widgets allow only the owner to see the contents underneath them by allowing the light that coming from one direction to pass through them. They also “consist of a scattering foil on top of an acrylic spacer”. In addition, these widgets are tracked by a camera in order to detect their positions on the table to display information underneath them. What is more, these widgets also used as an input device by “attaching a strip of IR LEDs to the side of the widget”.

WeSearch [16] is a system that supports collaborative web search for groups around tabletop display. It provides four movable, rotatable, and scalable toolbars one for each user at the edges of the table. Through these toolbars, users can enter query terms or urls to open WeSearch browsers. In addition, each toolbar has three buttons: pan to scroll vertically and horizontally, link to link-following, and clips to divide the page to small chunks in order to have smaller clips on the table separated from the main page. The benefits of these clips are to divide the work between group members by sharing important content; these clips also can remain opened even if their parent is closed. Another feature of WeSearch is to divide the work between group members by clicking clips button after typing query terms, which will provide users with four groups of results: relevant images, clips of related web pages, summaries of news articles, and suggested query terms. Each toolbar in WeSearch interface also provides users with information about other users' activities such as clips and query terms.

2.1.3 Private Territories:

This type of interface is meant to be used by a number of individuals performing their tasks independently. These interfaces provide each user with a personal area to interact with and perform their tasks. Klinkhammer et al. in [2] implemented a tabletop system that provides each user with a personal territory. Their system tracks users around the tabletop through the use of an array of infrared distance sensors and provide information about user's position and movements. Based on this information, a personal area will be created for each user and will follow him/her as they move. In their system, no new personal area will be created if that will cause overlapping with others' areas. In addition, when two users get close to each other where they look at each other's areas, their area will remain next to each other with no overlapping. If those two users remain close to each other for 15 sec, the system will remove the area that was left to make more space for new users. They used their system as a museum application that allows visitors to explore museum exhibits independently and simultaneously.

In this research we present an example system of our proposed proxemics events model, where the types, size, and positions of territories will be dynamically changed according to the real-time user behaviors.

2.2 Uses Of Space In Real Life:

When talking about the use of space we can see that there are two different understandings of the meaning of space. First, there is “space in the geographic sense” that “is most commonly discussed with reference to the animal's territory or home”[39]. Second, there is the “personal space of the organism” [39] defined as “the distance that the organism customarily places between itself and other organism” [39]. The difference between territory and personal space is that personal space moves according to the organism who forms the center point of that space; but the territory has fixed position and its center is “the home of the animal or man” [39]. In addition, personal territories can be marked in different ways. First, in stationary spaces people specify a part of that space for themselves (e.g. desk in an office). In some other public situations, people use their bodies in order to mark their territories (e.g. seat in a dining hall) [42].

ProximityTable considers the use of both meanings of space that we discussed earlier (territories and personal spaces). It uses personal spaces of people (proxemics) to mark personal territories similar to marking territories in public spaces. As a person reaches the display, his/her personal territory will be marked by showing a personal workspace on the display. In addition, because the personal space moves according to people’s movements in real life, ProximityTable makes personal territories (workspaces) follow their users as they move.

Edward Hall expanded the meaning of personal space and introduced proximity theory in his 1965 book “The Hidden Dimension” [5]. Proxemics is defined as how a person perceives and uses the immediate space around him/her. Hall identified four distance zones around each individual: intimate distance, personal distance, social distance, and public distance as shown in Figure 1. In real life we can observe different situations where people aim to protect their personal spaces. For example, people prefere to stand in a crowded train or subway where they can have more distance from others than sitting on an unoccupied seat in a more crowded region (e.g. in middle seats between other commuters) [40]. In addition, it has been found that student's seat sellections in classroms is affected by a number of factors including "performance" (e.g. avoid distractions while working), "social" (e.g. sit next to someone they know), "asocial" (avoid sitting next to anyone), "noticeability" (e.g. to capture the attention of others), and "environment" (e.g. try to or avoid sitting close to a door) [41].

ProximityTable considers both social and asocial factors. It considers social factor by allowing users to merge and split their workspaces when they come close to each other. Users also might increase the size of the workspace as onlookers come closer to the main user. In addition, ProximityTable considers asocial factor by allowing multiple groups or a group and individuals to interact with the display independently and simultaneously.

2.3 Proxemics And Interactive Displays:

Mark Weiser 1991 defined the ubicomp as "technologies that disappear, that weave themselves into the fabric of everyday life until they are indistinguishable from it, where computers are integrated "seamlessly into the world" [15, 38]. Nowadays, connecting multiple devices to become part of the environment still "far from seamless" due to the blindness not only of "the presence of other devices" but also of the "non-computational aspects (e.g. people and non-digital objects)" of the environment [15]. Here we can use proxemics to avoid this blindness. As stated before according to Edward Hall, proxemics is how a person perceives and uses the space around him/her, which was defined to four zones (intimate, personal, social, and public) [5]. In the case of proximity for ubicomp Saul Greenberg et al. stated five proximity measures: "distance between enitities", where "entities can be a mix of people, digital devices, and nondigital things", "orientation between entities", "identity", "movement", and "location" [15].

Proximity theory has been applied by a number of systems (both wall and tabletop interactive displays) in order to appropriately respond to user's behaviors. Applying such theory requires using a tracking system to track users around the display. This section will take a look at a number of systems that applied proxemics theory through the use of different tracking technologies.

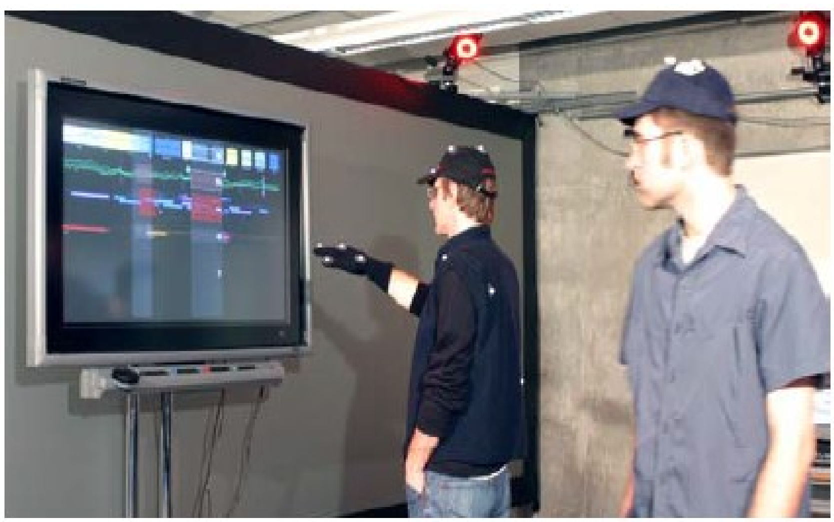

Figure 3: The use of Vicon system in Vogel and Balakrishnan [12]

Vogel and Balakrishnan in [12] applied Hall's Proxemics theory to a wall display scenario and identified four interaction zones that could be enabled by tracking the position and orientation of users. In their study they tracked user position and orientation according to the wall display in order to detect levels of engagement with the display, leading to changes in how the user interacted with content on the display, and in how that content was presented. They have four interaction phases based: first, “Ambient Display” that is initial status of the display where users should quickly understand the general concept of the system. Second, “Implicit Interaction”: as users pass by the display, the system will enter this phase and “infer their openness to receiving information” [12]. Third, “Subtle Interaction: When the user approaches the display and provides an implicit cue such as pausing for a moment, the system should enter the subtle interaction phase” [12]. This phase is meant to be used for a short period that only to allow users to choose an item on the display to brows. Finally, “Personal Interaction” is the last phase where users should get closer to the display and start browsing the contents. In order to track users around the display, they used Vicon motion tracking system that provides information about location and orientation of different part of user’s body.

Medusa in [13] is another example of applying proxemics theory to interactive displays. It is a tabletop interactive system that uses Microsoft Surface as an interactive display and a set of IR-based proximity sensors to track body, arms, and hands of users. IR-based proximity sensors are divided into three arrays: outward array on the display’s sides for body tracking (long range 10-80 cm), and outer (long range 10-80 cm) and inner (short range 4-80 cm) arrays facing upward on the perimeter of the display for arms tracking. Based on information from proximity sensors, touch points will be mapped to a specific user and hand.

In addition, Proxi-Sketch, an application for creating and editing prototypes of graphical user interfaces, was developed to explore a number of new interactions through the use of sensing system. In Proxi-Sketch, a “blurry, blue glowing orb” [13] will appear as a user enters the tracked region (with in 80 cm around the table). The focus of the “glowing orb” will increase as the user gets closer to the table. This “glowing orb” will be removes if the user left the tracked region.

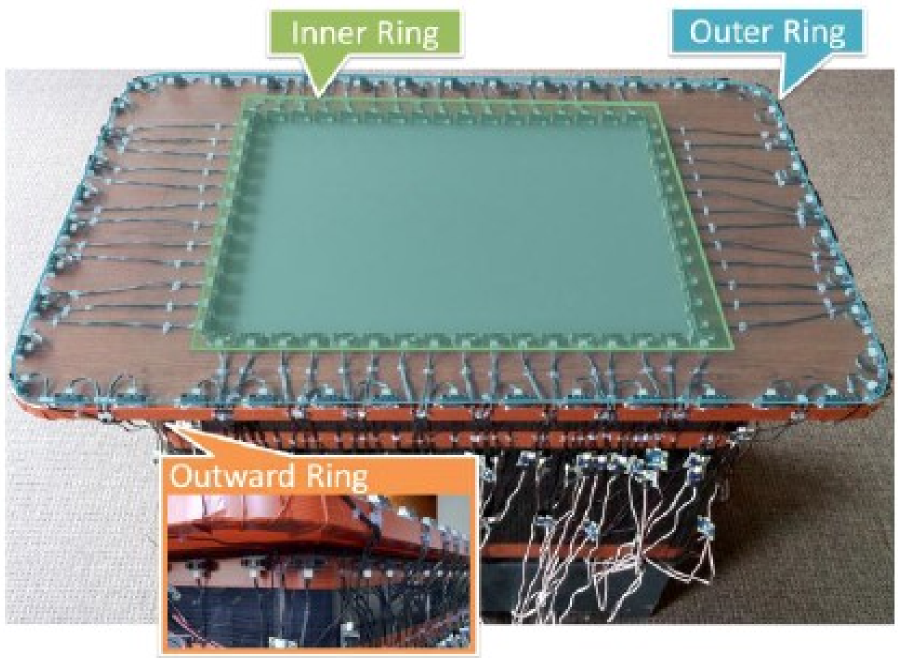

Figure 4: IR proximity sensors were used in Medusa [13]

Proxemic Media Player application [14] is an application that not only reacts to people’s movement and orientation but also to their personal devices and other objects. Location and orientation of users, digital devices, and other object was tracked through the use of Vicon motion tracking system. Based on the information from tracking system, user’s distance to the display and other objects and their movements and orientation, changes on the wall display application will occur. For example, when a user enters the room and as s/he gets closer to the display, the system will start and continue displaying content on the wall display. They system will allow user to brows content through touch interacting as s/he stands in front of it. It will also switch to full screen as the user sits. Some other interactions are pausing videos that playing on the display as the user turn his/her head away from the screen or start a phone call; and playback videos when uses look back to the display or finish their phone call.

Tran-Surface [22] is a system that allows users to transfer information between a shared display and mobile devises. It uses NFC tags, which installed at the edges of the display, to track the position of mobile devices around the display. Tracking the positions of mobile devices leads to knowing the positions of their users. Scanning NFC tag will create a portal in both mobile device and shared display. When a user wants to change his/her position s/he should move to his/her new position and scan the NFC tag on the new position which will move the portal to the new position. Through the use of mobile devices, users can browse the web and select what they want to share on the shared display. By dragging the selected items to the portal on the mobile device, these items will be transferred to the shared display and positioned in front that user. Dragging items to the portal on the shared display will provide users with three options: Delete items from the shared display, share items with mobile device, and search on the mobile device based on these items.

Screenfinity [23] is a system that tracks users around large vertical display in order to increasing the perception area of content. It responds to users' movements by moving, zooming, and rotating the content in order to allow them to read while passing by the display. The content will be displayed on the screen as the system tracks users. The content also keep moving as users move and zooming in and out as the distance between users and the display change. In their pilot study, they used Optitrack, which is motion tracking system, in order to track users. In their field study, they replaced Optitrack by 10 depth cameras (5 at each side of the display) to track users even if they are not in front of the display.

Bootstrapper [34] is a system that tracks users around an interactive tabletop display. It uses users' shoes in order to identify them through the use of depth cameras that installed at the edges of the display. It first captures the shoes and then compares that image with the database; if there is match, it will show that users data and if not, it will match that image of shows to that new user.

Each of the previous tracking systems has limitations that make them not ideal to be used in our system. For example, using IR-based proximity sensors does not allow to track users who stand behind the one who is interacting, so that make it not ideal for tracking groups. Using NFC tags require the use of extra devices, which is not convenient in many cases. In the case of Optitrack system, it requires a large number of cameras and specific setup which costs high and is not easy to deploy. Our tracking system (DT-DT) uses only one Kinect camera, does not require users to use or wear extra devices, and tracks users at and around the tabletop display effectively and efficiently.

2.4 Group Formation Around Public Interactive Displays:

Public interactive displays are opened for use by a different number of people as individuals, pairs, and groups of three and more. Such usage by pairs and groups can be different in terms of how they gather around the display, do all members interact with the display or not. If not, do the rest get involved in discussion and how. This section will look at systems that are aimed at exploring this aspect with interactive displays.

TouristPlanner [18] is an interactive tabletop application that was developed to explore how public walk-up-and-use tabletop displays can be approached and used by groups. It allows four users as one group (each at one edge of the display) to use the system at the same time. Each user has a rotating fan (contains 20 cards of different places to visit) in order to only choose up to three places to visit; no one can proceed to next step until all members have their choices. After they complete their choices and chose to proceed to the next step, the system will place all the chosen cards (from all users) on one side and same orientation to encourage the discussion between group members about the selection; if they agreed then they can print full plan of the selection. In Marshall et al.'s study, there were 158 individuals, 184 people in pairs, and 183 in groups of three and more who interacted with the system; those numbers will increase if they include those who did not interact with the system. From their study they found that it is rare for groups to arrive at the display at the same time; and when they get to the table, sometimes some members leave the table while other are still interacting. They also found that in some cases groups are joined by complete strangers. In addition, some people used only one side of the table even if the rest was available to use; the reasons they indicated in the interviews are some of them did not notice that more than one user could use it simultaneously, and some others preferred to have a joint focus.

If such system was proximity-aware, the interaction would be much better. For example, if the system knows that there are three people standing on one side of the table, it might notify them that there is a chance for the other two to work independently. If they preferred to work as a group, the system might increase the number of cards that they would choose. In this case also the system might allow other individuals or groups to work independently form the first group using the rest of the table.

In Azad et al.'s work [19], they identified a number of patterns of how people gather and use existing vertical displays, including group identification and positions. In their field study, they observed people using three different public displays: "Cinema Ticket Kiosks", "Photo-Developing Kiosks", and " Mall Directories". From their observations they found that group formation (e.g. they are all next to display or one leader and two look over his shoulders) is affected by how people reach the display (e.g. they all moved at the same time or one lead the group to the display). They also found that group formation sometimes changes during the interaction session. In addition, they divided group members into three categories: "driver" is the member who is interacting with the display, "active observer" is the one who always helps the driver ("closest to the display"), and "passive observer" is the one who is not involved in the interaction. In terms of multiple groups using the display, they found that group formations are also affected by the number of groups around the display. What is more, they found that groups position themselves based on their arrival time ("first to arrive is closest"); they also reposition themselves when a group leaves the display.

These findings tell us that the number of participants within the group, number of groups, and group formations might change over time. Therefore, tracking users and detecting their position according to the display and other users is important to support collaboration around interactive displays. For example, size, orientation, and position of the content on the display might change based on individual position within group and group position according to other groups.

2.5 Tabletop Toolkits:

By reviewing the researches on tabletop display and its applications, we can see the increase of providing different toolkits to support the work on tabletops including collaborative work, differentiating users, etc. We discussed some of such systems in previous sections such as WeSarch [16] and Interface Current [29]. Another example is Truong et al.'s work [45] where they introduced virtual keyboards for multiple users to be used in a collaborative work. They used a non-touched surface to project keyboards and other contents. They also used a Kinect camera in order to capture touch points and convert them to keyboard events. What is more, they provide users with "Word prediction" function to help increasing the typing speed and detection accuracy.

Tang et al.'s work in [17] is another system that shows three presentation techniques that support tabletop collaboration by completing tasks as a group or independently. First, filters provide multiple layers of global information on the workspace. Second, lenses which provide the same information as filters but localized. Third, shadowbox, which allows users to copy any area of the table to a movable window to allow more than one user to work on the same data set at the same time. Filters are designed to support group work since they provide single view of the context. Lenses and shadowbox both can support individual work since they both allow users to work independently without disturbing others.

Carpus [46] is a system that uses a high-resolution top-down camera to differentiate between users and a link each touch with its users. It uses the dorsal hand regions as users' identities.

2.6 Research Gap:

By looking into the existing vertical displays work, we can see that proxemics has been applied in different ways at and around the display. For example, Vogel and Balakrishnan [12] applied users' proxemics relevant to the display, where they detected levels of engagement with the display. Proxemic Media Player application [14] applied proxemics not only between users and the display but also between users themselves, and between users and digital\non-digital devices. In the case of horizontal displays, users are only tracked at the display. For example Klinkhammer et al.[2] created a private workspace for each user at the display. Another example is Medusa [13] which tracks users and their arms and hands. To the best of our knowledge, no one has applied proxemics to horizontal displays in a way that it tracks people not only at the display but also around it; and defines the relation between users around the display as well. This research applies proxemics between users and the display, and between users themselves in order to support the collaborative work around tabletop displays.

Chapter 3: Architecture

This chapter will discuss the objectives of ProximityTable framework implementation (section 3.1). It will also briefly describe the tracking system that ProximityTable use (section 3.2.1). Section 3.2.2 will describe the implementation process of ProximityTable and its features. Lastly, section 3.3 will discuss lessons learned during implementation phase.

5.1 Implementation Objectives:

From the related work, we can see how the use of tabletop displays to support collaborative work has been increasing through a number of domains. We believe that providing a system that is not only able to support one group around a tabletop display but also support multiple groups around a single tabletop at the same time will allow for better interaction. For example, if there is a group working on a project using a tabletop display, at one point they might divide themselves into subgroups to work independently on smaller pieces of the project and come together later on to combine their work. Recognizing and supporting grouping and ungrouping will allow users to divide and combine their work smoothly. Another example is when the system is able to recognize and support multiple groups at the same time; multiple groups might use it simultaneously as an information station at the entrance of a museum. To provide this support, we wanted a system that allows us to explore how proxemics can be used to support collaboration around interactive tabletop display by:

- Being able to differentiate between single user and group of users, knowing the size of groups, detect their positions around the tabletop display, proxemics of individual relative to the display, proxemics of individual relative to another individual, bystander vs. active user, detect the presence of a new user, and the absence of an existing user.
- Providing developers with a set of proxemics events according to position of single individual relative to the tabletop display or to another individual, in order to support collaborative work around tabletop displays.

Requirements	Justifications
Single vs. group	To support highly and lightly coupled tasks between group members [1, 2, 17]
Size of group	To provide each group with a private workspaces that matches the size of the group, similar to the concept of private workspaces for individual [2]
Proxemics to the display	User's position and distance relevant to the display, which are important proximity measures [15] (e.g. detect level of engagement [12])
Proxemics to another individual	User's position and distance relevant to another user, which are important proximity measures [15] (e.g. when to remove a workspace [2]). This includes user's position within a group, group formation, breakup of group, changes in group membership.
Bystander vs. active user	To give bystanders the chance to involve in the discussion and/or the interaction (there were 257 bystanders out of 986 users [2])
Presence of a new user and absence of an existing user	These are important features to have in the system (e.g. to know when to turn the system on and off [14]

Table 1: System requirements

5.2 System Implementation:

We can see from the related work that existing interactive surface systems use three different ways to track users around the display: through the use of IR sensors around the tabletop, through some systems that require users to wear sensors (e.g. Vicon) or through the use of extra devices (e.g. mobile phones to scan NFC tags). For our prototype we were looking for a tracking system that would not require users to wear any sensor or use extra devices, which means using systems similar to Vicon and NFC tags would not be suitable. We also were looking for a tracking system that is able to detect and differentiate between users, groups, number of group members, and not only track immediate users but also who is standing behind him\her, which also make using IR sensors not suitable for our prototype. Based on that, we decided to use top-down camera to track users around the interactive tabletop.

3.2.1 DT-DT System:

Dal Top-Down Tracker (DT-DT) is a top-down tracking system that provides human detection, tracking and action recognition via a single top-down 3D camera. It is comprised of a saliency-based human body detection model, a hierarchical tracking framework, and a 4D spatiotemporal human action classifier. In addition, a configuration and management tool allows for quick setup and control, and a socket-based communication package is adopted for integration with distributed interactive applications. It uses OSC communication protocol, which "is a protocol for communication among computers, sound synthesizers, and other multimedia devices that is optimized for modern networking technology" [21] to send information (e.g. ID, X, Y, and Orientation) of tracked users to any interactive application. More details about DT-DT can be found in [20].

DT-DT primarily has been developed for another project (My Mother's Kitchen [20]) that has different scene constraints, and tracks up to two users at the same time. In this work, DT-DT was extended and customized in order to support proxemics scenarios around the tabletop with more users (up to four). First, the tracking boundaries are setup by the edges of a tabletop. The entering and exiting zones of the system are redefined, which helps to reduce the searching space. Secondly, since the multiple users may stand very close to each other, the tolerance of target overlapping is increased to avoid ID switching or missing. Furthermore, according to the tasks of our proxemics tabletop application, a user less likely comes back again if exits the tracking region, so we reduce the thresholds for remembering him/her. Thus the user region will be immediately cleared when she/he finishes tasks and leaves. Those changes increase the robustness and efficiency of DT-DT in our proxemics tabletop system.

As shown in figure 5 that currently only two sides of the table are tracked because the Kinect camera has to be placed higher in order to track wider area and our lab has low ceiling. There are two ways to overcome this limitation. First, using Microsoft Kinect version 2, which might tracks a wider region around the display. Second, using multiple Kinect cameras, where each camera tracks different part of the tracked region and then process the data from each camera in order to get the final position from full tracked region.

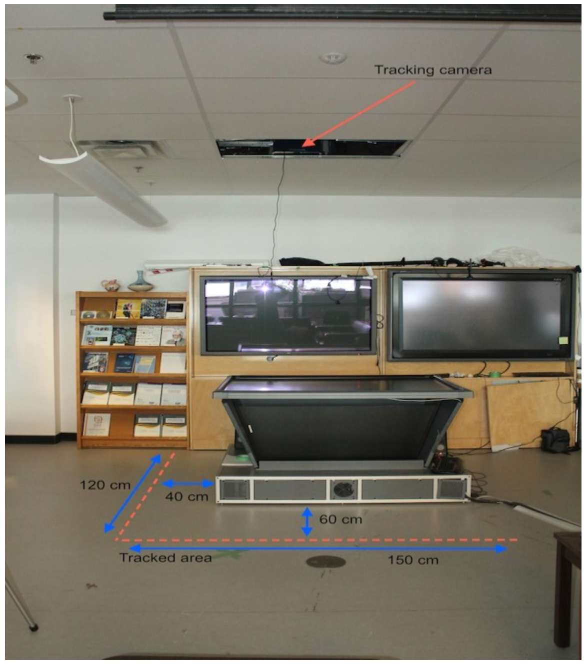

Figure 5: ProximityTable setup

3.2.2 ProximityTable Architecture:

In order to track users around the tabletop, we placed a Kinect camera 3.2m height above a 70" horizontal display. Figure 5 shows the setup of ProximityTable. Currently, one-way communication is established between DT-DT and ProximityTable, where DT-DT system sends users' data to the tabletop application via the OSC protocol. ProximityTable then generates a set of high-level events to support collaborative around the interactive display (described later in this section). ProximityTable receives messages only form DT-DT and the integration between proxemics events and UI event left to developers.

Using C# and Microsoft Surface 2.0 SDK, we developed a WPF surface application framework that receives user tracking data (Id, X, Y) from DT-DT system, and generates high-level events (proxemics events). The use of these events depends on the application where developers can use our framework as another source of information and choose what events to listen to. In addition,

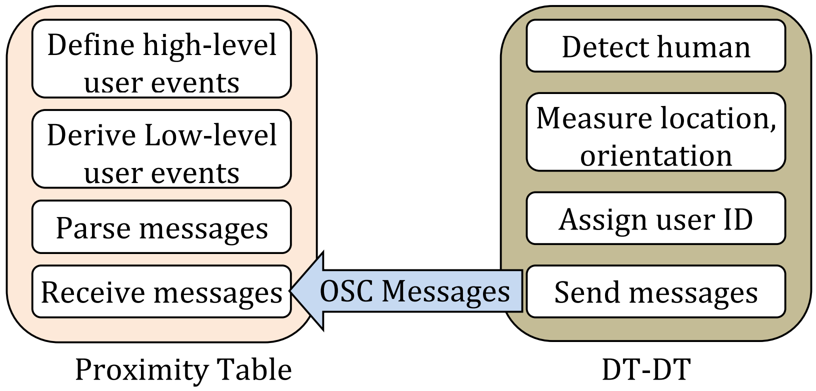

Figure 6: Framework architecture

developers also can use our existing tools to generate new proxemics events byfollowing the following steps:

1. Determine proxemics events, will take one of our events as an example to explain these steps (e.g. approaching event). For this event, a developer should determine a distance according to the display to generate the event (this distance depends on the type of application, tasks, environment, etc.).
2. ProximityTable framework has "ReceivedMessage" class where it takes low-level events (received data "ID, X, Y, Orientation"). This class also contains a number of methods to generate events (e.g. GenerateApproachingEvent). A developer can register to listen to our existing events or he can use user's data in order to generate his own proxemics events. When a user enters the tracked region, approaching event is generated and fired. If a developer registered for this event (e.g. approaching event), he will be notified as soon as the event fired.
3. At application level, a developer can generate any response to the fired event (e.g. create a personal workspace for that user).

ProximityTable framework receives all users' data (ID, X, and Y for each user) in one single message and then processes this data and stores them separately to start generating high-level events. Figure 7 shows this step. In our current we disabled orientation detection feature in DT-DT due to enabling that slow the detection process. The Z-axis is fixed, where the Kinect camera can track different body sizes without capturing any noise data caused by the lights from display. Currently, we are not using the header of the message but it can be useful to be used in the future. For example, it can be used as an indicator to at which side of the table that user is standing.

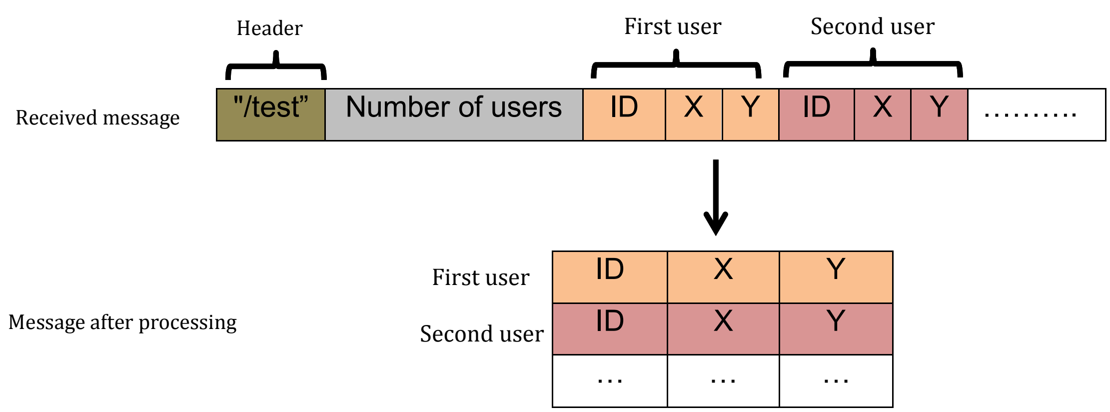

Figure 7: Message before and after processing

In order to accurately detect users positions according to the tabletop display, we first started by measuring the length of each side of the table through the Kinect camera and identifying the start and end points of each side (length of long side is 1.25m and short side is 0.95m). Our model consists of low-level events, high-level events and responses. Low-level event as the following:

- Detection event: this event is generated once for each user as s/he enters the tracked region.
- Moving event: this event is the base of other high-level events, such as approaching event (as will be discussed later in this section); where we can trigger any response based on the application. Users' movements within the tracked region around the tabletop display will generate this event. Responses for this event can be moving some game pieces based on users' movements such as Body Pong in [36]. It also might allow users to move their documents or workspaces with them as they move around the tabletop display. Since we have top-down tracker, the system might allow users to pass behind others, which is an advantage of DT-DT tracking system over other systems that uses IR-proximity sensor (e.g. Medusa in [13]) where the system cannot detect users behind other active ones, as they move with their workspace or game pieces.

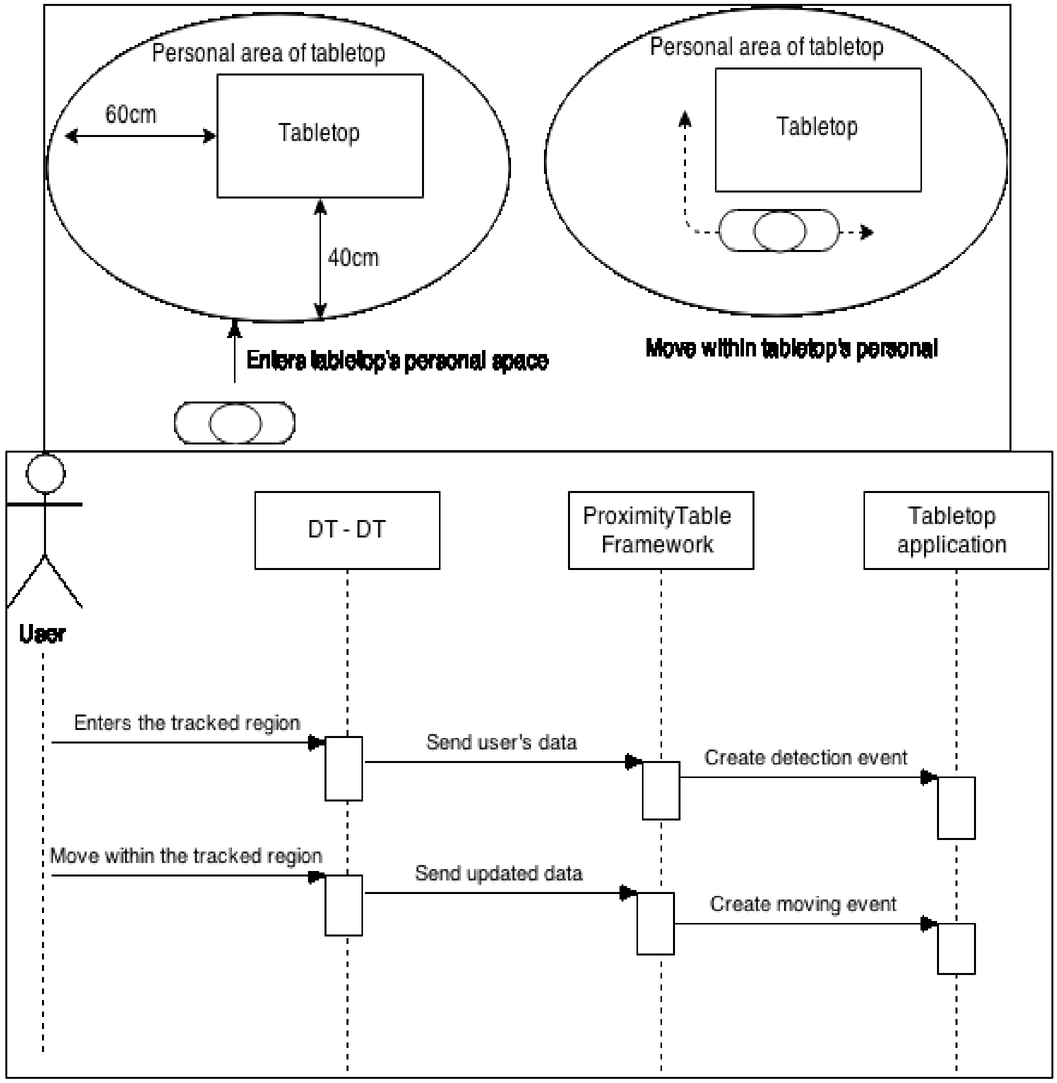

Figure 8: Create Detection and moving events

As we stated before in Hall's proxemics theory [5], space uses are defined: intimate, personal, social, and public spaces. Based on the low-level events and the rules of two space uses (intimate and personal spaces), currently our system is able to generate a number of high-level events (proxemics events) as the following:

- Approaching event: since we had a limited tracked region, we assumed that the personal space of the table is the tracked region (currently within

150 cm “long side” X 120 cm “short side”, with 60 cm and 40 cm in depth accordingly). In our current settings approaching event will be generated as a new user enters the tracked region around the tabletop, within the personal space of the table. We chose this region due to the limited tracked space around the display; but distance and regions can be different based on type of application, tasks and environment (e.g. approaching might be generated when a user from one zone to another when having wider tracked region). Figure 8 shows this step. This event can trigger any response based on the application. For examples, it can display a number of controllers right in front of the user or automatically drag controllers to the user to show them what they can do with interface. Another example could be establishing a private workspace that has all controllers for that user to interact with. A third example could be playing some sounds that explain how to use the interface or how to play the game. The idea of generating responses that belongs to a specific user is based on territories marking in the real life. For example, people can mark their territory by “spreading out belongings” [43] on a table; so if we present something on the display for that user as they reach it, that indicate that region of the display belongs to that user.

- Leaving event: this event will be generated when a user leaves the tracked area, out of the personal space of the table, (figure 8 shows this step) where the system can trigger a number of responses. For example, remove workspaces or documents that belong to the users who left. If all

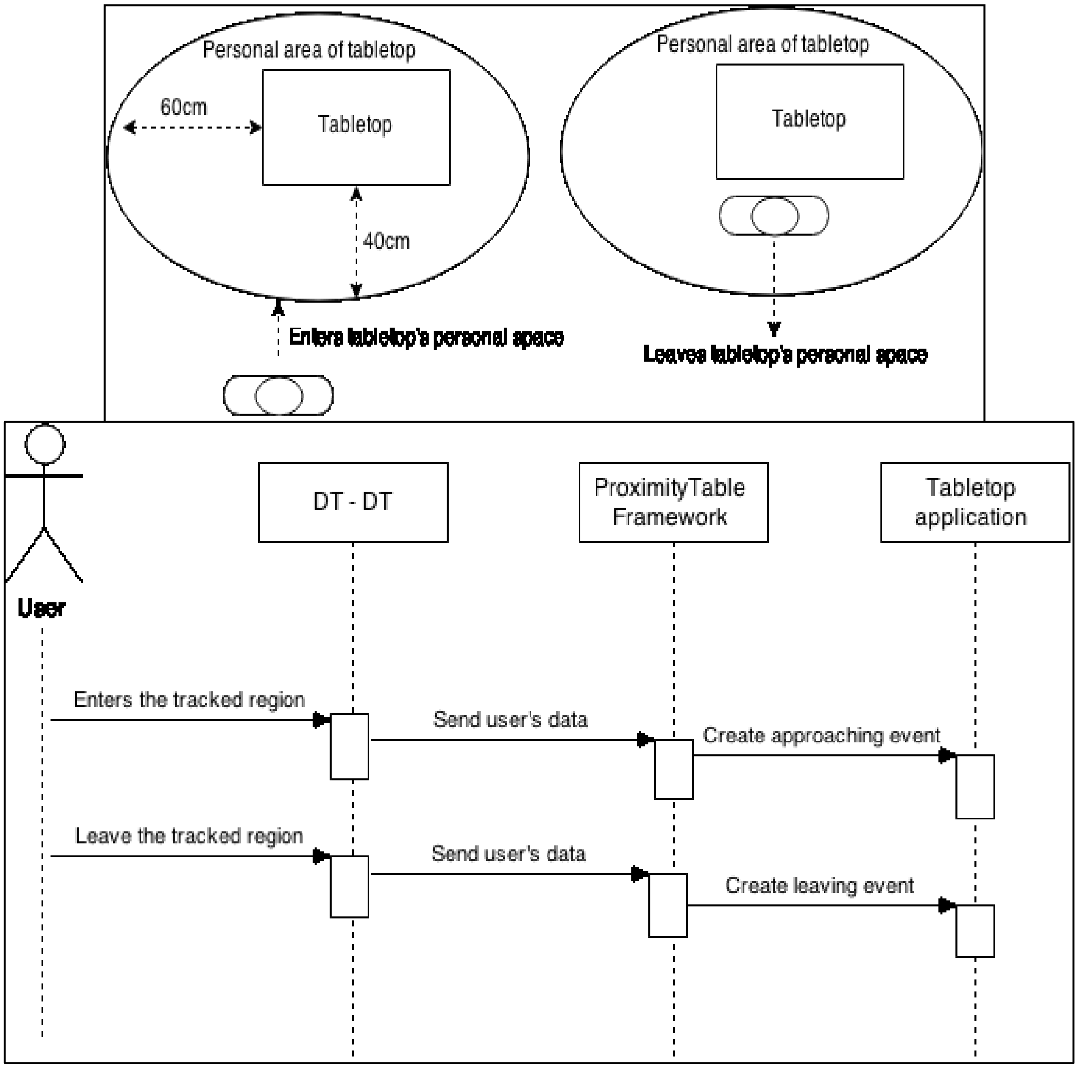

Figure 9: Create approaching and leaving events

users left the tabletop display, the system might play some videos to capture the attention of passersby. The idea of removing items belongs to users from the display as they move also based on real life observations. For example, in Azad et al.'s work [19], they stated that group formations might change during the interactions due to role changes (e.g. "active observer became driver"); these changes occurred because the driver finished his/her interaction session (e.g. buy a ticket at cinema kiosk) and leave the to allow other group members to start their sessions. In that situation, when a user leaves, his/her data will be removed and the device will be opened for new users to start new sessions.

- Grouping event: this event will be generated when the distance between two users or more is less than a predefined group formation threshold, i.e. one user is within the intimate space (less than 45 cm) of other user. There are a number of response examples that the system can trigger for this event. First, the system might change the position of the documents based on the positions of both users. In the case if each user has his/her own workspace, the system might give them an option if they want to join their workspaces. The system also might increase the content on the workspace if there is an onlooker. In terms of group movements, our current settings generate moving event based on the movements of the main user.
- Splitting event: this event will be generated when the distance between two users was less than a predefined group formation threshold and become more than that threshold, i.e. a user left the intimate space (more than 45 cm) of other user. Responses for this event would be the opposite of grouping event’s responses. Examples include splitting joined workspace into two smaller workspaces, decrease the size of the content, and move the documents to their original position.

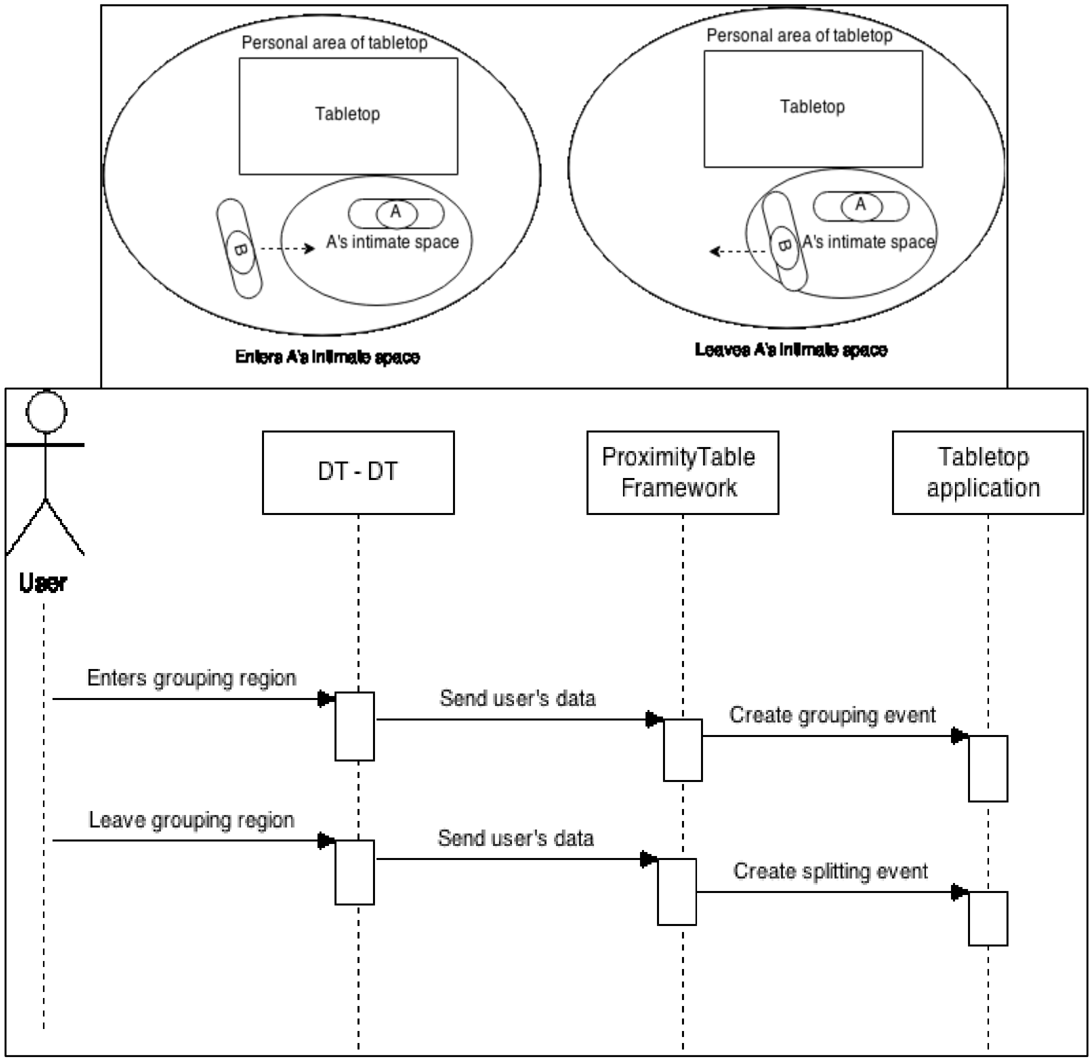

Figure 10: Create grouping and splitting events

- Switching orientation event: this event will be generated when a user moves from one side to another side of the table, assuming that users are always facing the table. A possible response for this event could be rotating documents or workspaces according to user's position.

➢ Recognizing onlookers: this event will be generated when a new User B enters the intimate space of an existing User A (within 45 cm), where we assumed User B is trying to look at what User A do; In that case, the system will recognize User B as an onlooker. Responses for this event can be notifying User A about the by stander ask if s/he wants any interface changes (e.g. increase the size of the workspace).

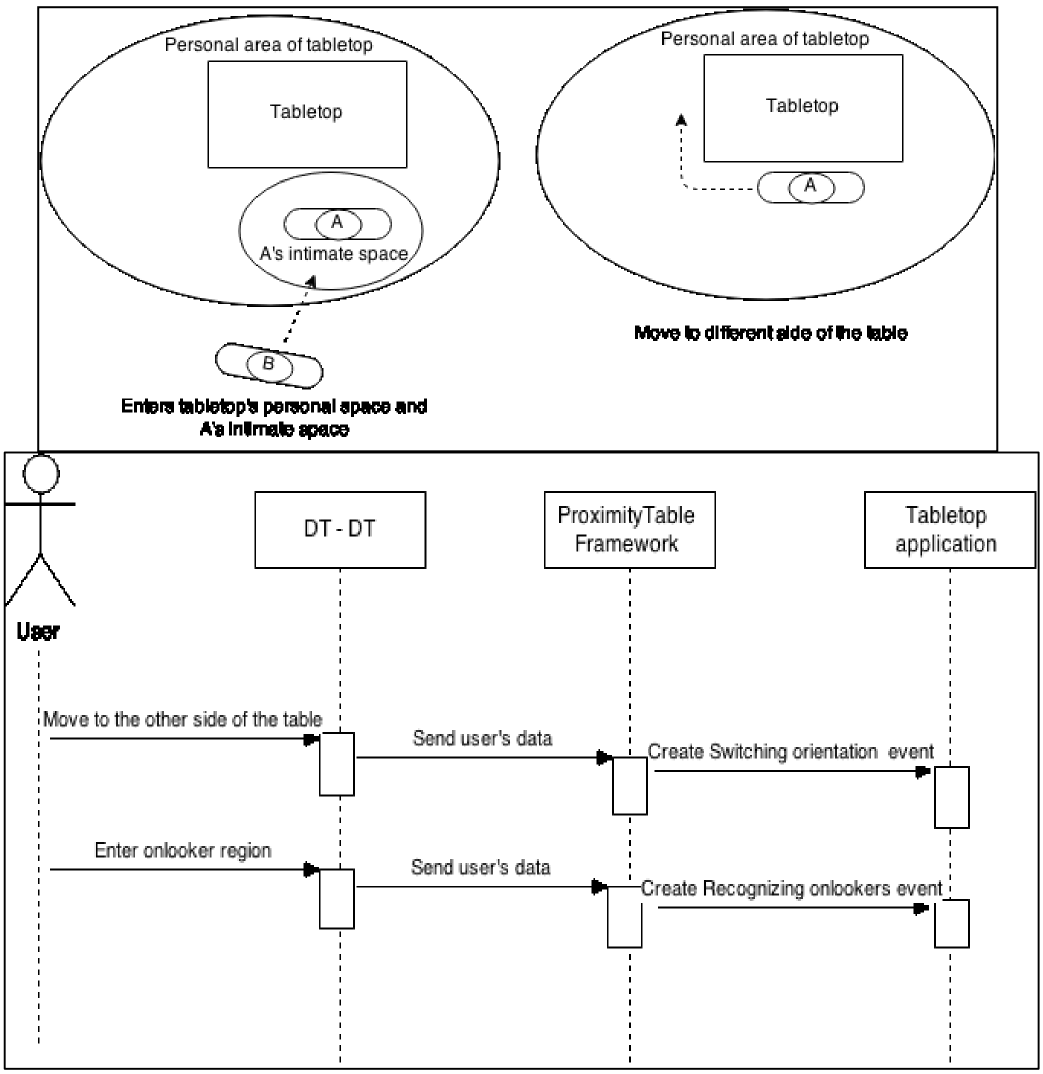

Figure 11: Create switching orientation and recognizing onlookers events

We used the intimate space threshold of Hall's theory as grouping and splitting threshold because we believe that if two people are trying to work on the same documents they will break into each others' intimate spaces; also if someone is trying to look over someone's shoulder to see a document that person holds, s/he should get into that persons intimate space. Personal space threshold of Hall's theory was used as approaching and leaving threshold because we believe it is the appropriate distance from the tabletop display to inform users of the openness of the display to start new interaction session; although one side of the table generate approaching or leaving events with a distance that less than the personal space due to the limitation of the tracked region. As stated by Hall in [5] that these distances can be affected by a number of factors such as culture, we also believe in proximity-aware system these distances can be changed based on the type of application, tasks, environment, etc. As stated earlier this chapter developers need to set a threshold between entities (e.g. users and table or users themselves) and check if users within that distance the event and its response will be generated.

As we stated before there are five dimensions of proxemics for ubicomp that Saul Greenberg et al. described in [15]: "distance", "orientation", movement", identity", "location". In our model we have covered the distance between users and display, and users themselves as well as their IDs and movements. We also covered the location by identifing the position and dimensions of the display. In terms of the orientation, DT-DT can detect the orientation of the users but we did not enable that in our model due to processing delay that detection cause.

Our model consists of seven events and each of which was chosen for a reason. Detection and movement events are fundamental event that inform the system of the presence of users and their positions. Approching, leaving, and switching orientation are important to know when to present, remove, or switch direction of the contents in the display. Lastly, grouping and splitting events are the main contributuion of our system, which allow us to generate responses in order to support group or multiple groups at the daisplay.

We have a limited tracked region because the Kinect camera need to be placed higher in order to track more space. Due to that, there is no a specific distance between users and the display to generate our proxemics events, users only need to be within the tracked region. But if we improve the tracking system (having multiple cameras, use Kinect 2) as will be discussed in the future work later, we can identify a specific distance form the table for each proxemics event. This can be done by getting the position of the user at each side the tabletop through the Kinect camera and set them as “end-points”; then get “start-points” by identify the edges of the tracked region that we want the system to generate events in. In other words, detect positions of table and users then set thresholds (e.g. within 50 cm from the table in each side, 30 cm between users). There for, developers can use our proxemics events and specify responses according to their applications, or create new proxemics events and their responses also according to their applications.

3.2.3 Lessons Learned:

During the implementation stage we faced a number of technical challenges.

3.2.3.1 Depth Threshold In DT-DT:

DT-DT allows developers to change the depth threshold based on the placement of the Kinect camera, which will be for all users. This causes an issue when we have multiple users with different body heights; because if we set this threshold to a specific height and we have users taller than that threshold, the system will start to switch users' IDs or mix them as one user only when they get too close to each other or pass next to each other. In addition, if we set that threshold for taller users, short users might not be tracked. In our current settings, we reduced the impact of different body heights issue by setting the threshold where the Kinect at least can see heads of normal body height (1.7 m from the Kinect). The drawback of this approach is that sometimes it mixes tall users to one user when they stand close to each other. To avoid this issue we might improve DT-DT in a way that it can set a threshold for each user when they first detected. Kinect 2 also is another possibility that we might try to overcome this issue.

3.2.3.2 Lose Track Of Users:

As stated before that DT-DT sometimes lose track of users or switch their IDs as they pass or stand next to each other; DT-DT was improved by increasing the tolerance of target overlapping to avoid IDs switching or missing or mixing users when they pass next to each other or stand close to each other. This improvement does not solve the issue if users stand shoulder by shoulder. To overcome this issue, we might limit the size of the shoulder to its half, meaning the distance between the neck and the end of shoulder; so any body after this distance would be another user.

3.2.3.3 Orientation In DT-DT:

Another issue we had is using orientation data that DT-DT can provide. At the beginning we were planning to use orientation data as a low-level event and generate high-level events to provide a number of responses. Examples of these high-level events and their responses as the following:

- Switching orientation event: where the system rotates documents or workspaces based on users' orientations.
- Grouping event: determine group formation when a users turn his/her body to face other's workspace.

When enabling orientation feature in DT-DT makes it much slower especially when there are multiple users because it processes a number of frames for each user to detect his/her orientation. To overcome this issue, we assumed that users are always facing the table, which allow us to easily detect their orientations according to their positions.

Chapter 4: A Prototype Application Using ProximityTable

We used ProximityTable to implement a prototype application for two purposes. First, we wanted to demonstrate how ProximityTable framework can be used to create useful tabletop interactions. Second, we also wanted to evaluate a number of proposed proxemics-driven system behaviors. We identified a number of responses for proxemics events to test how effective it is to use them to support collaborative around tabletop displays. This chapter will discuss the prototype application by stating each response and defining how they occur.

• *Creating/removing workspaces:* to create or remove a workspace (personal territory), the prototype application is listening for approaching and leaving events (currently when a user enters or leaves the tracked region around the tabletop). When approaching event is fired the prototype will create a personal workspace for that user; and that workspace will be removed leaving event for that user is fired. Flowchart in figure 13 shows how the system handles these events.

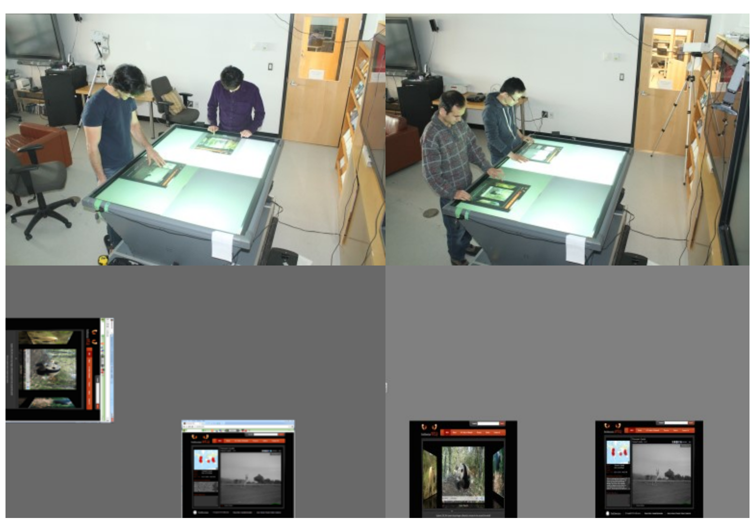

Figure 12: Individuals at ProximityTable with their workspaces

• *Moving workspaces:* to move a workspace (personal territory), the prototype application is listening for moving event (proxemics event) and button touch down event (UI event). Moving event will be fired when a user moves within the tracked region around the tabletop display, where his/her workspace will follow him/her as s/he moves. This can be enabled/disabled via a button on the workspace itself. Disabling this feature allows users to leave their workspace still and move to work at another workspace or discuss others' work. In addition, when a user passes behind others as s/he moves with his/her workspace, workspaces will be Z-Index ordered to make sure we do not disturb others' work by making the workspace that moves pass under the one that does not. Flowchart in figure 13 shows how the system updates the position of workspace.

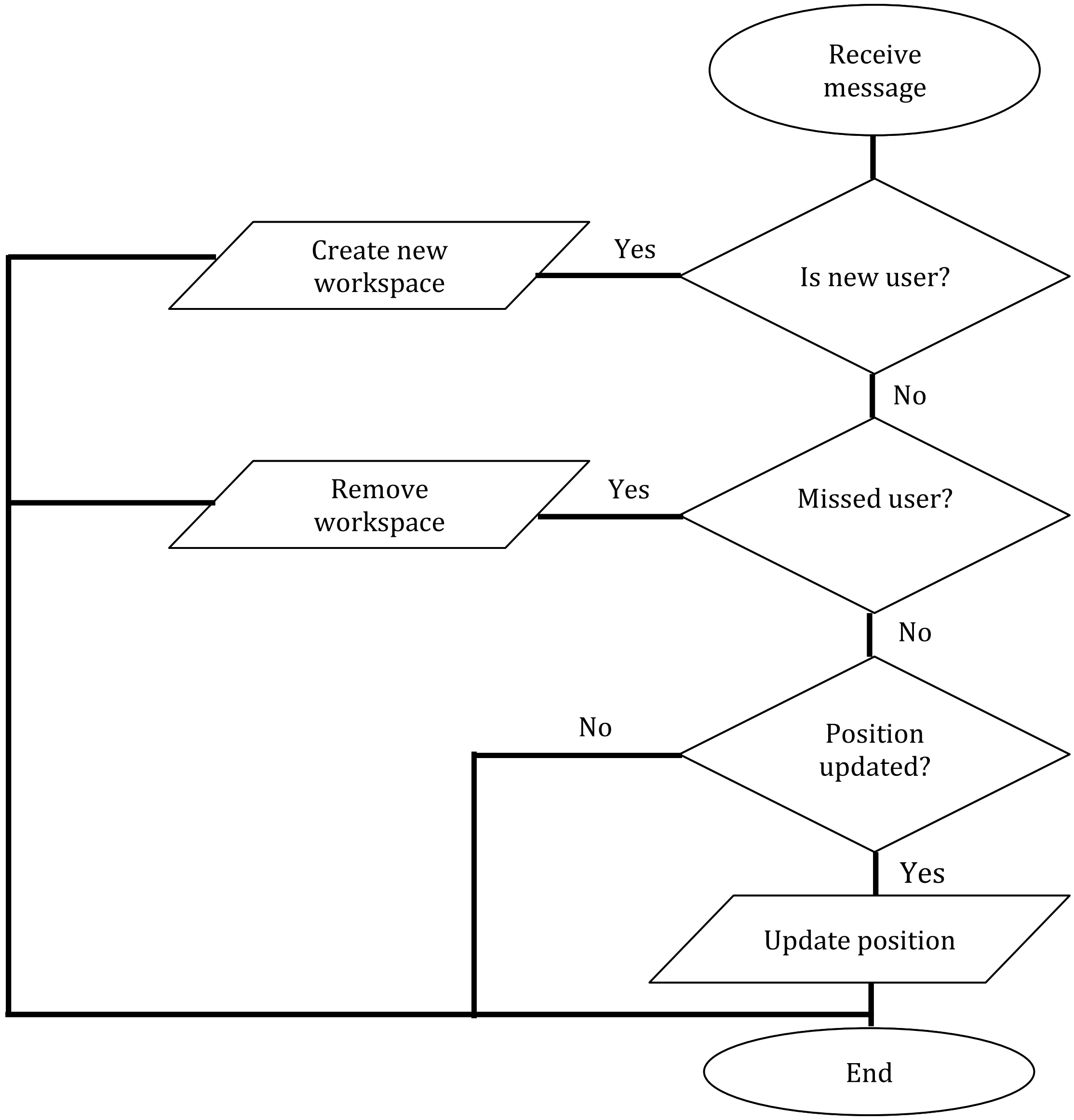

Figure 13: Creating, removing updating position of workspaces events

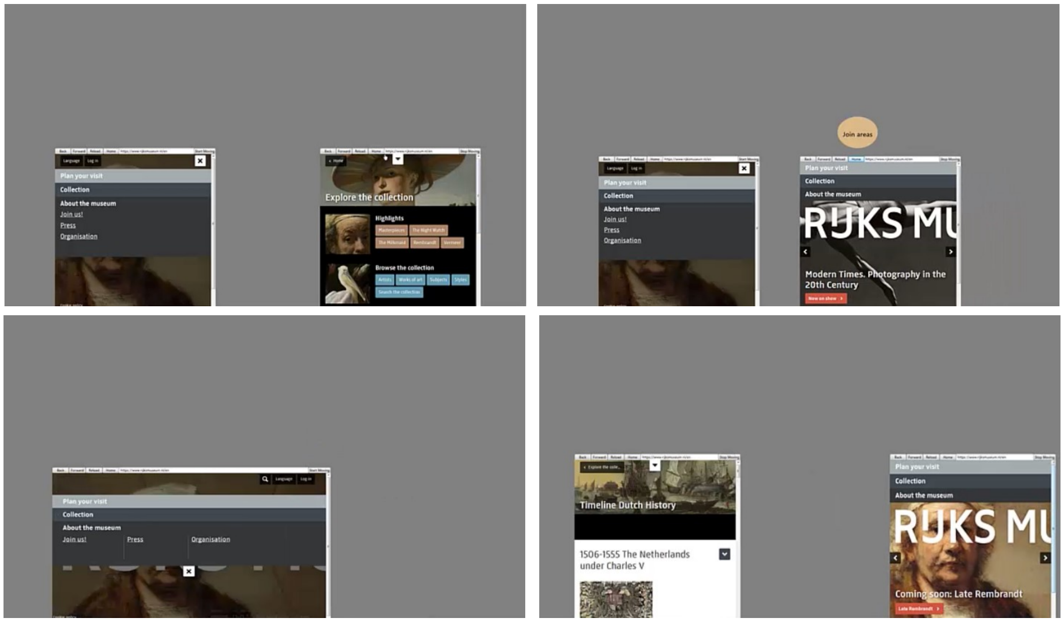

Figure 14: Two users stand apart from each other (top left), two users got close to each other and formed group that made "join button" appear (top right), two users joined their workspaces (bottom left), two users separate their workspaces (bottom right)

• *Grouping and splitting:* the prototype application is always listening for grouping event (proxemics event) and it will be fired when User A moves into the intimate space of User B to give users the option to join their workspaces, where the prototype shows "join areas" button. As soon as the button is displayed, the prototype starts listening for button touch down event (UI event); when the user touches that button, A's workspace will be removed and the size of B's workspace will increase. Comparing what our prototype provides for groups with existing work, we can see that our prototype provides groups with more space (suitable to group's size) to interact with where others such as Klinkhammer et al.'s work in [2] removes one workspace and leave the group with normal size workspace. Our prototype also gives users the chance to ignore join option and keep both workspaces. In addition, when the user touches "join areas" button, the prototype starts listening for splitting event (proxemics event). When splitting event is fired, our prototype reverts the size of B's workspace to normal 5 seconds after the last person has left their intimate space. A workspace for A will be created once they leave B's threshold and remain at the table. If we go back to Azad et al.'s observational study in [19] we can see a variety of different group formations around public displays. Due to that, our main purpose for this feature is to adapt the size of workspace to the number of users at each one to provide users with better interaction. Flow charts in figures 17 and 18 show how the system handles these events.

Figure 15: Different sizes of workspaces according to the number of users at each workspace

• *Recognizing onlookers:* the prototype is always listening to recognizing onlookers event (proxemics event) that will be fired when a new User B enters the intimate space of an existing User A (User B does not have to be at the table). When this event is fired, the prototype shows "increase area" button where starts listening to button touch down event (UI event). If User A touched the button, the size of the workspace and its contents will increase. If the user chose to increase the size of the workspace, the prototype will start listening to leaving or approaching events (proxemics event). Leaving event will be fired when User B leaves both intimate space of User A and tracked region; and approaching event will be fired when User B leaves the intimate space of User A and move somewhere else at the table to receive his/her own workspace. Look at figure 16.

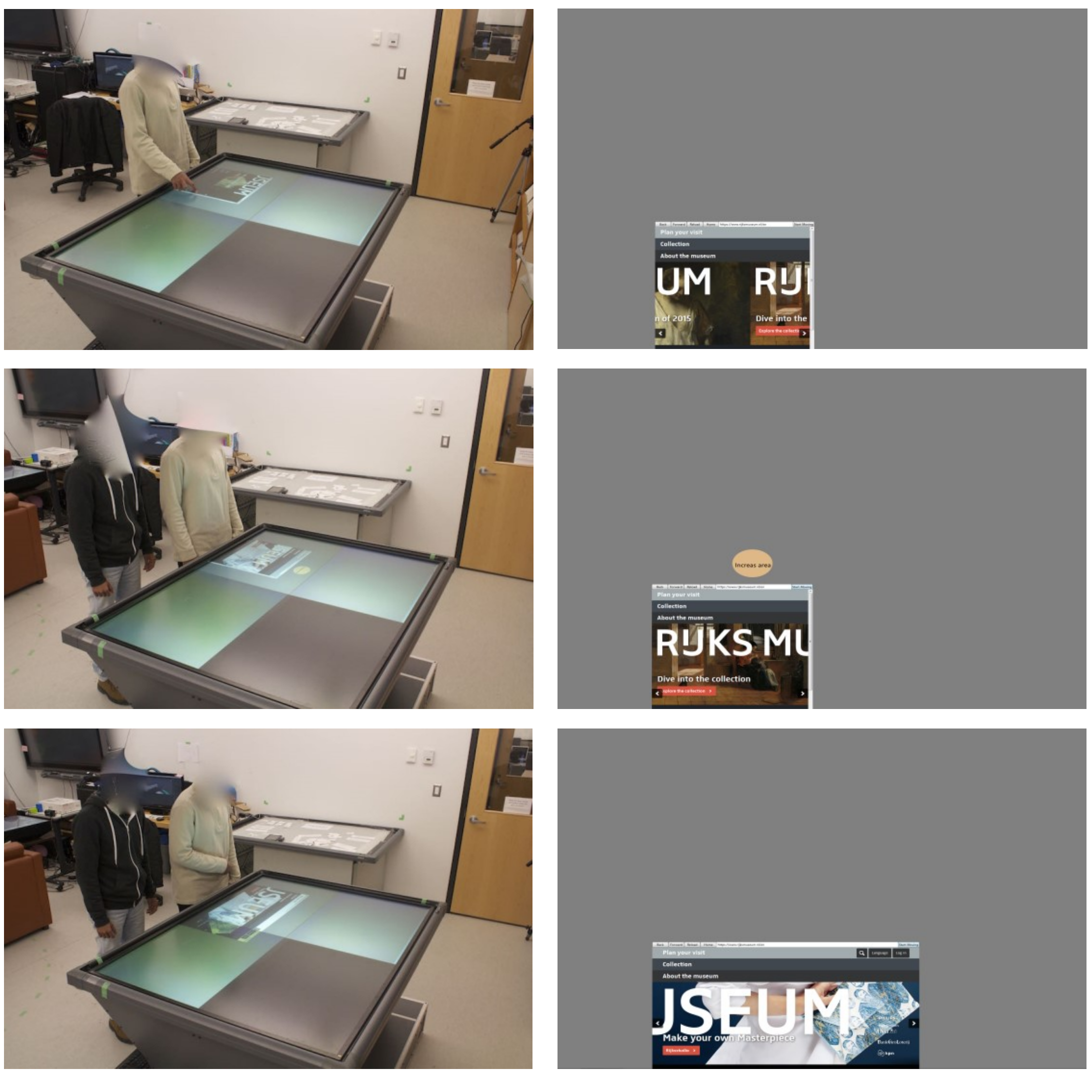

Figure 16: One user using ProximityTable (top), a new user reach the table within the intimate space of the existing user; the system recognize the new user as onlooker and notifies existing user (middle), the existing user chose to increase the size of the workspace (bottom)

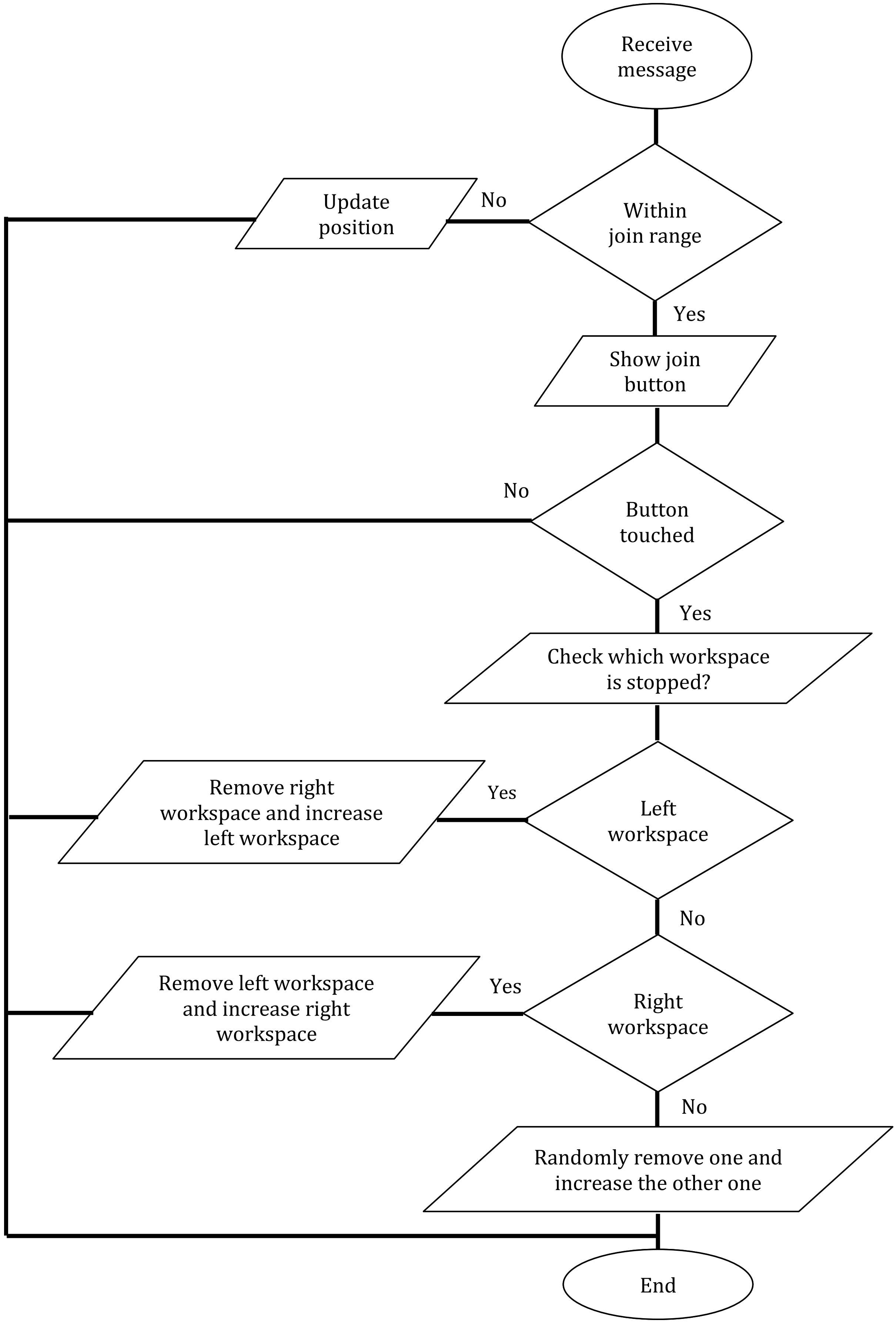

Figure 17: Joining workspaces in ProximityTable

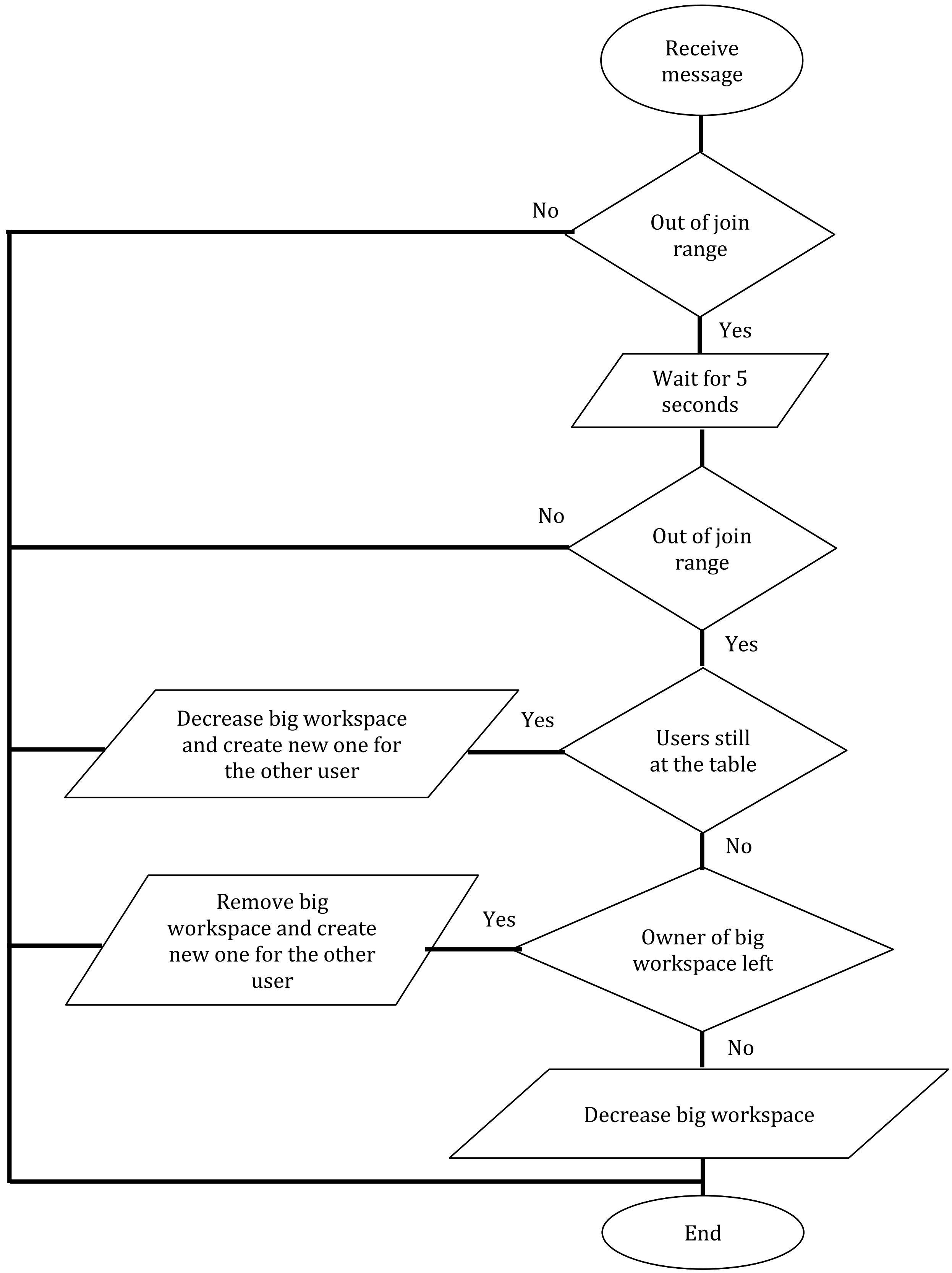

Figure 18: Splitting workspaces in ProximityTable

Since we assume we will use such system in public places, ProximityTable was implemented as an information station to be placed in the entrance of the museum where each workspace contains a website of a museum (www.rijksmuseum.nl/en). Figure 19 shows a snapshot of ProximityTable workspace. Figure 20 show a hierarchical informative of different sections of the chosen website. When click on “Explore the collection” (figure 20 up-left), it will presents a list of headers of the contents of the museum. Going from there to “Works of art” (figure 20 up right), we can see a number of sections (figure 20 bottom-right) that contains collections of items (figure 20 bottom-left) and short texts about each of these items (what is it? Which year? Etc.).

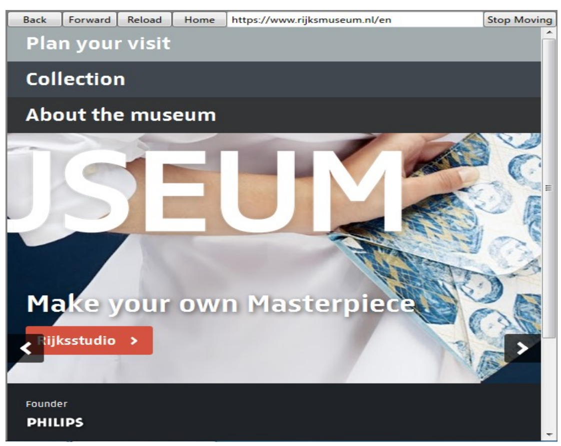

Figure 19: A website in ProximityTable workspace

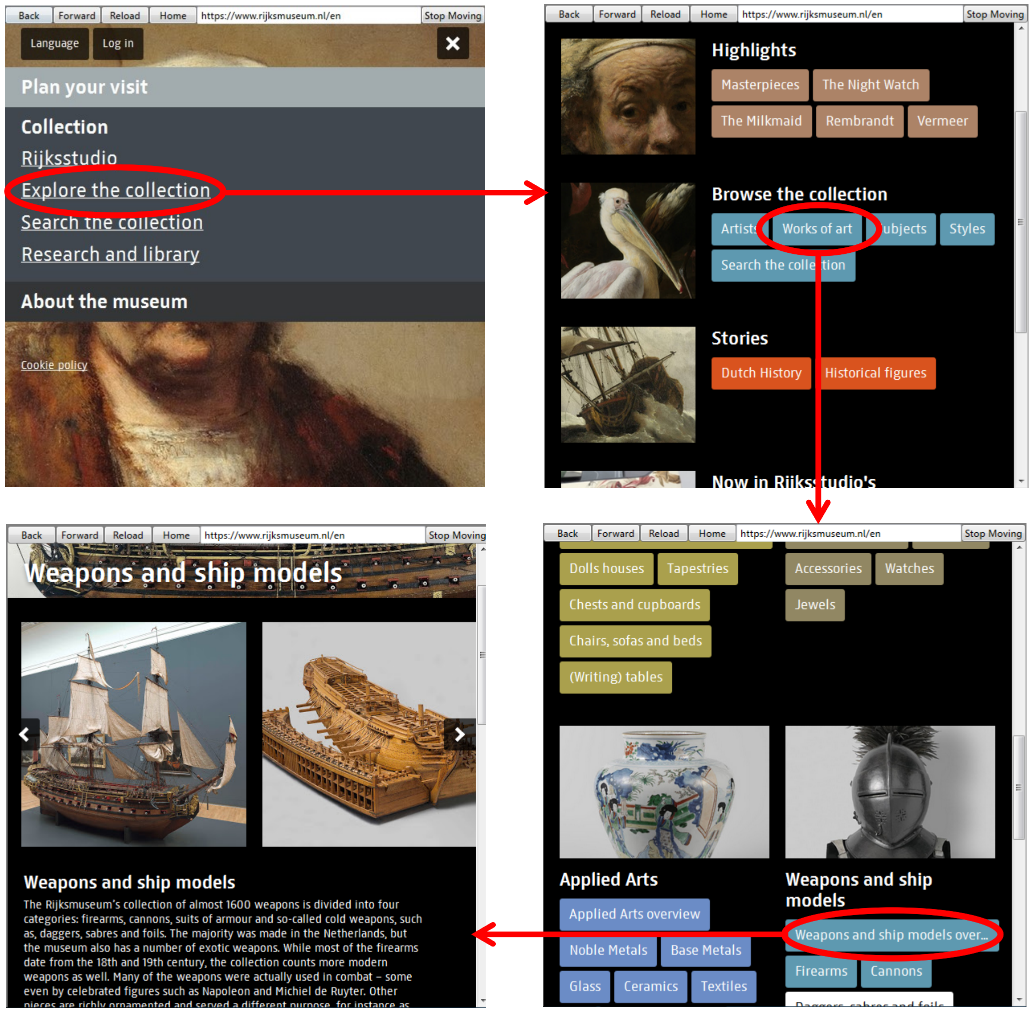

Figure 20: Different sections of the website

While implementing this prototype application we faced a challenge that is having multiple browsers in a single tabletop application to interact with at the same time. Since we are using Microsoft Surface SDK we thought that using WPF controls along with surface SDK would allow responding to multiple touches on these controls. So, we started by using "WebBrowser" control that is provided in MSDN libraries; and we found that it does not allow parallel interaction with more than one web browser. In fact, only a number of these controls can recognize multiple touches at the same time (e.g. canvas). Due to that we tried to build a transparent layer to place it on top of every thing in the interface, where it will receive users touches and convert them to moues events and send them to the application; but we could not do that because WPF does not allow to place any control on top of “WebBrowser” control. Then we found “awesomium“ API [32] that is HTML UI engine, which allows multiple users to interact with more than one “webControl” at the same time. This API allowed us to have multiple web pages and interact with them in parallel. There is only one issue with awesomium webControl that we noticed; it does not allow users to scroll by dragging the content; the only way to scroll is through the scroll bar. That tells us that identifying all the requirements and also identifying the tools that can support these requirements before the starting the implementation process will save a lot of time and effort; because we might get to a point where we have to change the way that the application should work due to the limitation of the tools we have.

Chapter 5: User Study

In order to evaluate the prototype application we conducted a focus group study. This chapter will discuss the research objectives (section 4.1). Then, it will describe the study design (section 4.2) including tasks, data collection, location, participants, recruitment, informed consent, compensation, and analysis.

We chose the focus group approach for a number of reasons. First, it allowed us to collect data from multiple individuals at the same time. Second, it encourages participants to become involved in discussion and express their opinions and experiences about different aspects of the work (including their experience of using the system, envisioning different scenarios where the system could be used). Third, it allowed us to elicit alternative designs in a paper prototype brainstorming session. In sum, the focus group allows us to know what our participants think about different aspects of the system, and to understand why they think that [44].

5.1 Research Objectives:

This research explores the following research questions:

1) *What user behaviors should trigger a response from the interactive tabletop?*

We wanted to evaluate the behavior-triggered responses defined in ProximityTable. Our system recognizes behaviors that allow responses to support collaborative work around the display (e.g. different styles of task coupling [1, 17]); to recognize these behaviors a number of proxemics events are generated (e.g. grouping events, splitting events, and recognizing onlookers events) as discussed in detail in Chapter 3. Our system also recognizes behaviors that inform tabletop applications about the presence and absence of users; based on these behaviors a number of proxemics event is generated event (e.g. approaching events, leaving events). We also wanted to explore if there are other behaviors that the system should recognize and respond to.

2) *Under what circumstances will users prefer automatic adaptation, symbiotic user-system agency, or direct user control?*

Klinkhammer et al.'s work [2] is an example of automatic adaptation, completely controlled by the system. We wanted to explore the scenarios where users prefer to take the control over the system themselves, to leave the system control, or control through actions taken by the users and the system. Knowing this will allow us to identify when to give the user control and when to give the system control. Indeed, it is possible that within the same interaction session users might switch between user and system control to perform a task.

3) *What kind of interface changes will best communicate group formation and dispersal, and the transition between an active user and a bystander?*

We wanted to identify interface changes that best communicate users' behaviors. These changes are responses to the recognized behaviors, which are meant to support collaborative work around the display (e.g. responses to group formation, splitting groups, and onlooker actions). These changes might include increasing or decreasing the size of a workspace, increasing the size of the content in the workspace, and shifting the workspace's location. Previous work has explored a range of responses to behaviors (e.g. switching to full screen as the user sits on the couch in Proxemic Media Player application [14], and detecting levels of engagement with the display in order to change how the content was presented based on the distance between users and the display [12]).

4) *How effective is it to dynamically adapt group work regions according to group size when more than one group is using the interactive table?*

We wanted to evaluate how effective our main concept of having multiple groups at a single tabletop, each with a workspace that adapts to the size of the group. Klinkhammer et al. [2] provide a workspace for each user, but we are aiming to provide each group with a private workspace. We believe that if it is effective to have multiple groups on a single tabletop that will open new opportunities for tabletops in a number of domains (e.g. classrooms) since we can have more groups per tabletop. To support this scenario, ProximityTable generates grouping, splitting, and recognizing onlooker events.

5.2 Study Design:

In order to evaluate our concepts, we conducted three focus groups with four members in each. The focus group format was chosen to generate qualitative and experiential data from a relatively small sample in a short amount of time. Each focus group was asked to: completing tasks using the implemented prototype, answering a short questionnaire, and participating in a discussion session.

5.2.1 Tasks:

After participants signed the consent form, the investigator explained the procedure of study. Each group was divided into two subgroups and they asked to start with a training task, where each group was given a paper with a task to be completed (Appendices C1 and C2). After completing the training task, they were asked to complete two main tasks. The first task was to find a number of items in the museum website to be found and it was divided into two sheets to give participants the chance to work independently each on a workspace or as group in a bigger workspace (Appendices D1 and D2). The second task was to plan a trip to the museum for school kids through the use of the museum website, which was in a single sheet to encourage participants to work collaboratively on a bigger workspace (Appendix E). After completing each task, each subgroup was asked to share an item that they found interesting. The goal of this sharing between subgroups is to discover how participants will share items across subgroups using the implemented prototype.

When both tasks were completed, they were asked to fill out a short questionnaire (Appendix F), to give each individual a chance to formulate and express their opinions. After they finished the questionnaire, they were asked to participate in a discussion session, where they watched video clips of the interface to help them to express their opinions. They also were given some time to brainstorm alternative designs and usages, where they were provided with paper materials to do so. Paper materials were used since it can be cut and shaped easily to form different interface layouts that allow participants to express their ideas easily. These materials consist of different sizes of blank sheets that represent workspaces, a number of documents (text, PDF, and webpage) in small pieces of papers, and a number of buttons on smaller pieces of paper. The material was prepared in this way to provide participant with a small set of interface elements so they can express their ideas. Outline of discussion is shown in Appendix G.

5.2.2 Procedure Of The Study:

The total time was approximately 75 minutes as the following:

1. Introduction, explained the study and signed the consent form (5 minutes).
2. Demonstration and training tasks (10 minutes): after giving a demo of the system, participants started with training tasks.
3. Completing first and second tasks (20 minutes): participants asked to complete first task then share an item with the other subgroup, complete the second task then share an item with the other subgroup. The time of each task was 10 minutes but when the time finished, participants were given the chance if they want to complete the task or move to the next one. While completing all tasks, participants also were given the option to work independently, each on one small workspace or as groups each two in a joined workspace.
4. Fill out questionnaire: 10 minutes
5. Participate in discussion (30 minutes): during the discussion we showed video clips of ProximityTable features to help participants to express their opinions, each feature was shown separately in a clip and then participants were given the chance to discuss the feature. Then we moved

to brainstorm and discuss alternative designs and uses of the implemented prototype, where participants were provided with paper materials (as stated in section 5.2.1) to make the brainstorming easer. Figure 21 shows a number of snapshots of using paper materials.

Figure 21: participants using paper materials to explain their ideas about interfaces designs

5.2.3 Data Collection:

We used video recording during the interaction and discussion sessions, software logging from the tabletop and the tracking sensor, and paper questionnaires. The video recording helped us to identify and track interesting behaviors that users did during the interaction sessions. It helped us to track behaviors across groups and detect how important these behaviors were based on the number of time they were repeated. In addition, video recording during the discussion helped for more understanding of users' feedback by tracking users' hands motions and moving materials while users expressed their opinions. The goal of using paper questionnaire was to allow participants to express their opinions before the discussion so others' would not affect their opinions.

5.2.4 Location Of Study:

The study took place in the Graphics and Experiential Media (GEM) lab, fourth floor, Mona Campbell building.

5.2.5 Participants:

We conducted three focus groups (each consists of four members): the first group G1 was a mix of grad and undergrad Computer Science students (3 males and 1 female), the second group G2 was Biology instructors (all female), and the third group was from Science Atlantic Association (1 male and 3 female). One condition of recruiting participants was that each group must be studying in the same major or working in the same department. We had this condition because we wanted participants from different departments with different background to use our prototype. This allowed us to have different opinions and feedback from a variety of backgrounds. It also helped us to see how such a prototype would be used in different domains.

5.2.6 Recruitment:

All participants were recruited by email announcements through Notice Digest (notice.digest@dal.ca), and Computer Science mailing list (csall@cs.dal.ca). In the recruitment notice, participants were asked to email their interest to participate to the listed researcher. The participants and researcher communicated to find an appropriate time for the study. The email and online recruitment script is shown in Appendix A.

5.2.7 Informed consent:

All participants involved in the study signed an informed consent form (Appendix B). This was administered by a researcher at the start of the focus group meeting. The informed consent outlined the risks and benefits associated with the study, a description of the study, the participant's right to withdraw without consequence, and assurances of confidentiality and anonymity of personal data. As well, the informed consent made it clear to participants that they would withdraw from the study without loss of compensation.

5.2.8 Compensation:

Each participant was compensated with a $20 Amazon gift card for participating in the study (whether they are able to finish or not).

5.2.9 Analysis:

As stated before, the focus group format was chosen to generate qualitative and experiential data from a relatively small sample in a short amount of time. We started our analysis phase with transcribing all videos including interaction and discussion sessions. Transcribing included timestamps for each participant along with what they said, and notes that explain users' motions to understand their ideas. We used oTranscribe, that is a free web transcribing app, to transcribe videos. We transcribed a total of 1154 lines (15976 words). When transcribing was finished, we coded our data trying to find interesting behaviors and trying to understand factors that caused these behaviors. We came up with six codes that are mainly based on the features that the system has. These codes are entering and leaving, moving, joining, splitting, overlapping, and other behaviors that are not within the previous ones. Under each of these codes, we have task related behaviors which occured because tasks required that. We also have interaction related behaviors, which occured because participant thought this is how it works, or they try to show their group mates how it works. Finally, we have technical issues related behaviors, which occured due to the technical issues participants faced. Classifying codes based on system's features allowed us to understand the relationships between users' behaviors, the impact of the interface design, and type of task on users. The analysis phase took approximately one month of work.

Chapter 6: Results

This chapter will discuss the evaluation of the implemented prototype application features including entering, leaving, moving, grouping, and splitting (section 6.1). All the percentages in this section were determined by the number of successful responses of each event according to the total number of them. Throughout this chapter each participant has his own unique ID (e.g. G1P3 means participant 3 of group 1). Section 6.2 will list technical issues and section 6.3 will state some alternative uses for such systems.

6.1 Evaluation Of Prototype Application Features:

6.1.1 Entering And Leaving:

These features were not heavily used because all participants came and left the table at once, but the system response accuracy for entering was 95%; we had two misplacement cases (the system did not place the workspace exactly in front of the user) and one case with no response. In the case of leaving the responses accuracy was 100%. When participants reached the table everyone in all groups looked at the table to see how the system created workspaces for users at the table. We noticed interesting behavior when participants P1G1 and P2G1 completed their task before participants P3G1 and P4G1. At that point P1G1 left the table to sit and wait for them to finish (figure 22). Leaving the table gave P2G1 more space and caused the system to reduce the size of the workspace, after which P2G1 moved left and right to make the workspace follow him: having more space allowed him to explore the moving feature, although not for a task-specific reason.

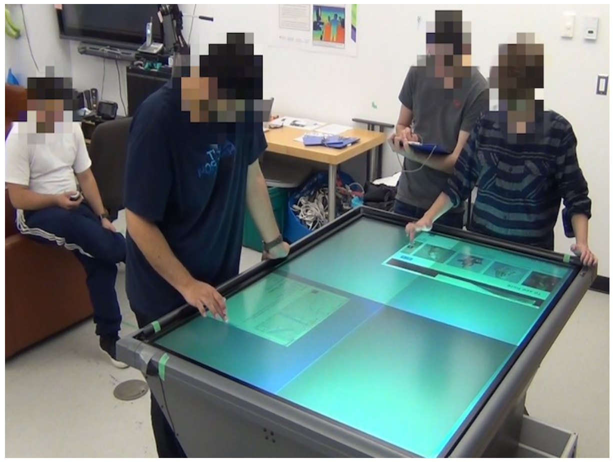

Figure 22: P1G1 left the table, P2G2 has more space

6.1.2 Moving:

Due to the limitations of table size and tracked region, our activities were not designed to require movement around the table, and we did not observe such behavior in the focus group activities. The system responds even to small movements with 100% accuracy, however, and so within the activities we do observe slight purposeful movements, for example when one pair wanted to prevent overlapping of their workspace with the other pair's workspace. All groups attempted to perform small adjustments in workspace position using touch more than once during the activities (figure 23 right). While this is perhaps because people are more used to moving screen elements by touch, doing small adjustments using body position was viewed as awkward by several participants. As P2G2 states:

"You know everybody felt like we get used to moving your hand so moving your body was a little bit more awkward to trying get the screen to shift"-P2G2

Another interesting behavior that happened only once across groups is when a P4G3 moved back from the table (left the tracked region) to make room for her partner P3G3 to move their workspace (figure 23 left), which caused the system to decrease the size of group area and create a new area for P4G3 when she came back because she left the tracked region. This might have happened due to the size of the table and tracked region (with a bigger table and/or tracked region P4G3 could move in tandem with P3G3 instead of going back). This also provides support for moving workspaces by touch.

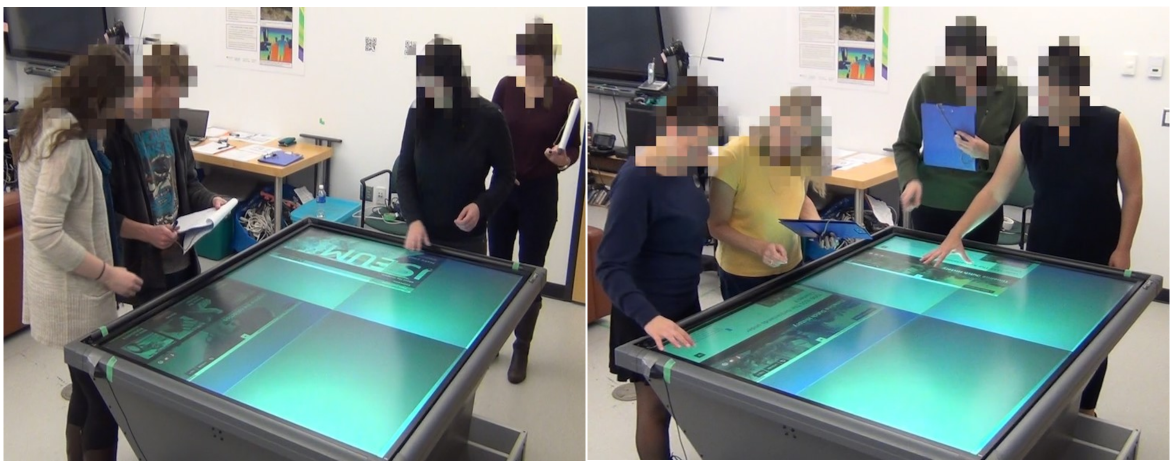

Figure 23: (left): P4G3 backed away to make more room for P3G3 to move their workspace. (right): P4G2 trying to move the workspace by her hand.

In addition, switching positions between subgroup members occurred at least once in each group, for a number of reasons. P1G1 and P2G1 switched their positions because P2G1 could not reach the scroll bar, so they switched and each remained in this position until the end of the tasks (figure 24).

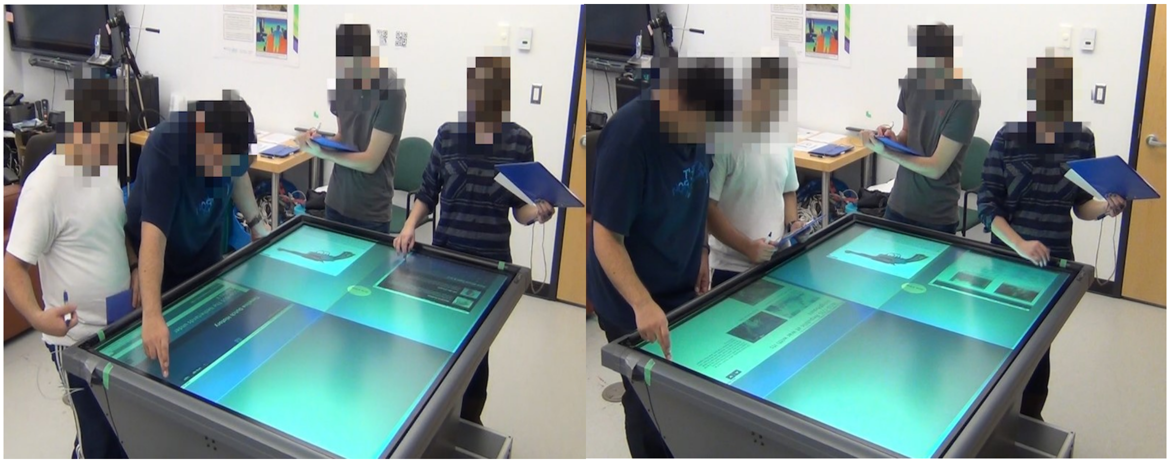

Figure 24: (left): P2G1 cannot reach the scroll bar. (right): P1G1 and P2G1 switch position

P1G2/P2G2, and P3G3/P4G3 switched their positions because they were trying to adjust the position of their workspaces to the center of their side of the table, but their workspace overlapped with the other subgroup (P1G2/P2G2) and moved to the other side of the table (P3G3/P4G3), which made them switch back (figure 25). As discussed, the interface provided an option to stop automatic movement of workspaces. Elven out of twelve participants set this option before they started their tasks or when workspaces started to drift a little left and right in response to their body movements. This option was kept for the entire task except three time where participants tried to avoid overlapping (twice in G2 and once in G3). P3G1 worked using his own browser/workspace, and he never stopped automatic movement, although he felt annoyed by that movement: during the discussion he said:

"I did not remember just stop the movement when I started and then just my casual movements like this will move my work; that was kind of annoying even, but if in a workplace environment anywhere where you have to move along a wall or something like that would be useful"-P3G1

P3G3 and P4G3 did not stop automatic movement until these movements caused the workspaces to overlap. At that point P3G3 and P4G3 moved apart then each stopped automatic movement of their individual workspace.

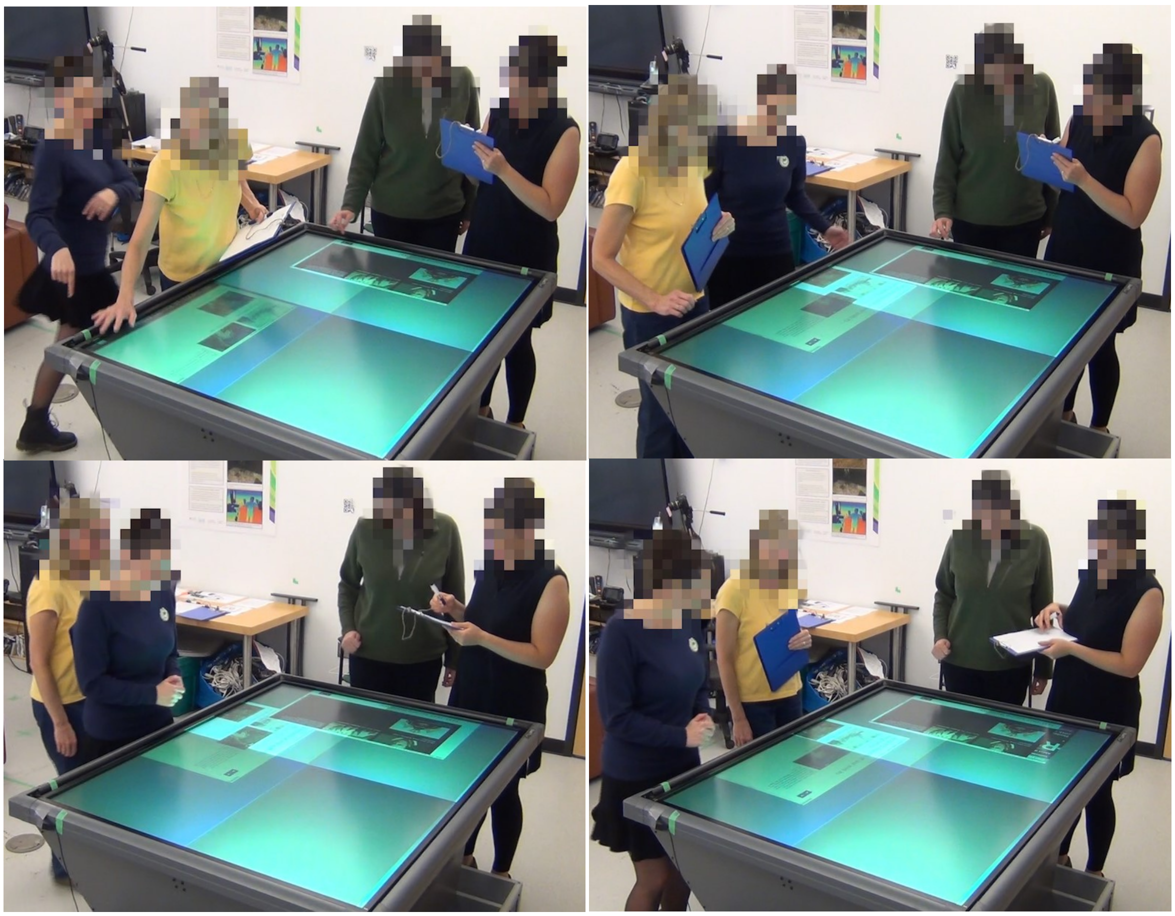

Figure 25: (up): P1G2 and P2G2 switched positions to adjust position of workspace. (down): P1G2 and P2G2 switched position back

6.1.3 Joining:

The system recognized join events with 90% accuracy. We had two types of tasks, and we attribute joining workspaces to the need to work closely together within a task, and to general collaborative style (highly coupled, lightly coupled, and uncoupled styles). In the training task and the second post-training task there was one activity that needed to be completed by each subgroup. For these tasks, five out of six pairs chose to join their workspaces for both tasks, while P3G1/P4G1 worked independently in the training task and joined in the second task. The first post-training task included two activities to be completed by each subgroup. These subtasks could be conducted independently, and then the results merged at the end of the task. Pairs P3G1/P4G1 and P3G2/P4G2 worked independently for this task; while the remaining 4 pairs worked on joined workspaces. While groups were mainly joined, there were some occasions of splitting the work in the middle of the task (will be discussed next section). Figure 26 shows examples of joined and independent work.

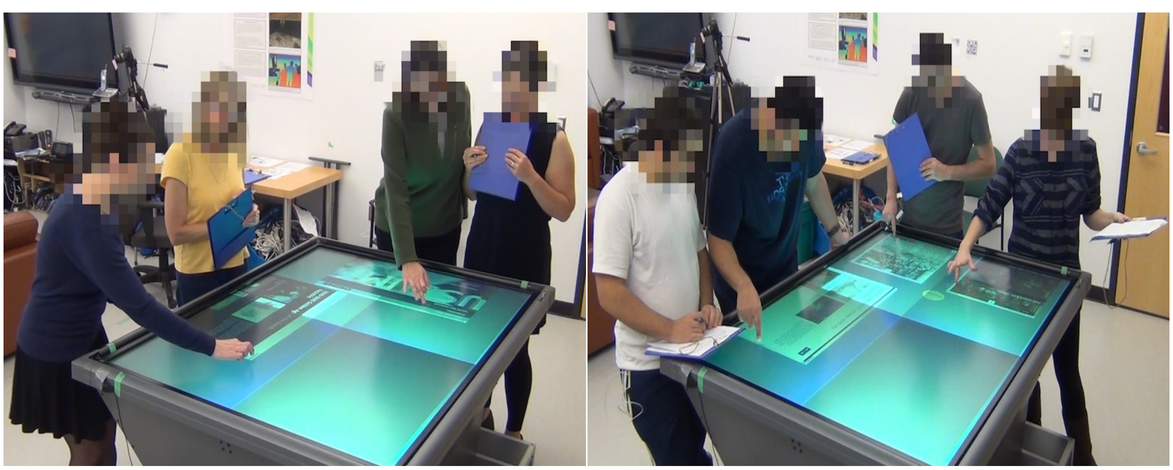

Figure 26: (left): P1G2 and P2G2, P3G2 and P4G2 working on joined workspaces. (right): P1G1 and P2G1 work on a joined workspace while P3G1 and P4G1 work independently

In addition, P3G2/P4G2 ended up working together using one small workspace due to a technical issue they faced (the system mixed and saw them as one user), will be discussed in section 6.3 (figure 27). To summarize, for tasks that could not be parallelized 5 of 6 pairs used a joined workspace and the 6th did so for the non-training task, whereas for tasks that could be parallelized 4 of 6 pairs still used a joined workspace, with the 2 remaining pairs doing parallel work independently, at least some of the time (see Figure 28).

Figure 27: P3G2 and P4G2 working on small workspace due to technical issues

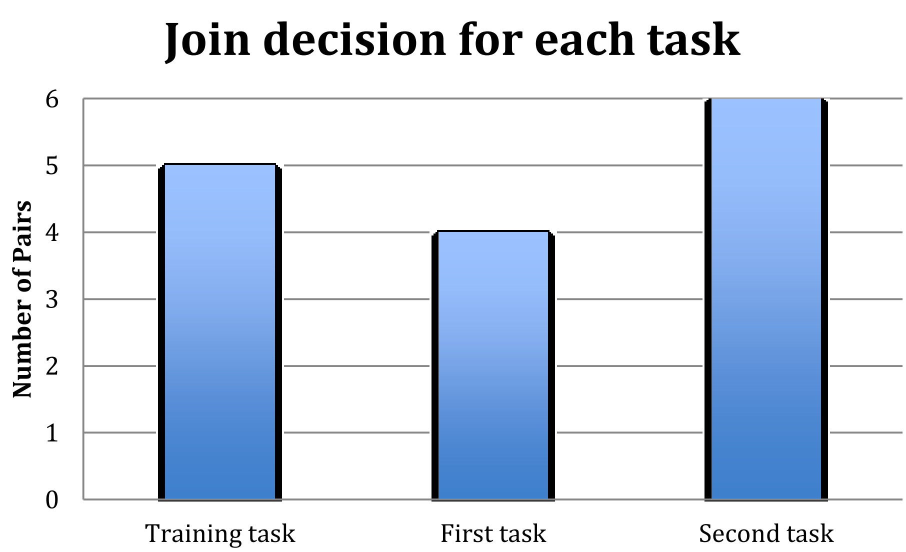

Figure 28: Join decision for each task

What is more, P1G3/P2G3 were not satisfied with the workspace's size and P2G3 tried to increase it using touch. Having a resizable workspace could be useful, as stated by a number of participants. Generally, with joined workspaces, each subgroup divided themselves into one interacting and one writing details and giving instructions ("driver and active observer" as stated by Azad et al. [19]) but sometimes the active observer interacted with the interface as well; this also support the observations of Azad et al. [19] about switching roles but in our case there was not role switching: the observer would quickly return to their normal role after interacting. This division was explicitly mentioned only once by a pair:

"Do you want me speak and you touch"-P4G3, "Ok"-P3G3.

In the questionnaire, 11 out of 12 participants agreed that adapting the workspace according to group size allows for better interaction. The decision to join was made sometimes collaboratively, and sometimes independently:

"Oh you joined us"-P3G2, "I did"-P4G2, "well done"-P3G2.

"Alright do you want to join areas again"-P1G2, "ok sure"-P2G2, "I like it when it is bigger"-P1G2.

In one instance, one pair (P3G3/P4G3) joined as a result of seeing another pair (P1G3/P2G3) do so:

"Do you want just establish" (means join areas)-P1G3, "yeah"-P2G3.

At this point:

"Ok, do you want to do that too"—P4G3, "yeah"—P3G3.

When participants worked independently there were two instances of collaboration using one of the individual workspaces. This happened when one member of a pair needed assistance. In the first instance one participant needed support with website controls (figure 29 right):

“I accidentally changed the language”-P3G3.

At that point her partner P4G3 touched the home button on her partner’s workspace trying to get her back to English; and then:

“I don't think that changes it back, oh it does alright”-P3G3.

The second instance occurred when P4G1 left her workspace and tried to explain to her partner P3G1 where to go to find what they were looking for (figure 29 left).

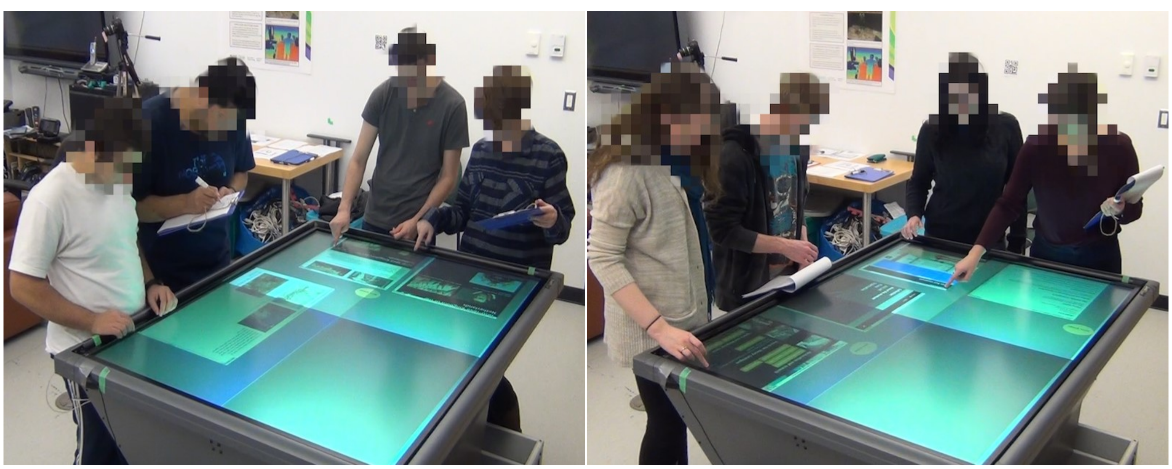

Figure 29: (left): P4G1 explaining to P3G1 on his workspace. (right): P4G3 touched home button on P3G3’s workspace

6.1.4 Splitting:

There were only three splitting events through the entire set of the tasks across all participants, where only two were correctly responded to by the system. In addition, there was one instance where the system incorrectly detected a split that was due to people being too close to each other and the tracking system seeing only one person. There were a number of interesting behaviors while splitting areas. First, at one point while completing the first task, P1G3/P2G3 decided to split the workspace and try to find the museum's floor plan in parallel. P3G3/P4G3 looked like they were motivated by that behavior and decided to split their workspace too (figure 30); when P4G3 noticed P1G3/P2G3 split their workspace, she checked the task on the paper then explained it to P3G3 and asked her if she want to split as well.

When P3G1/P4G1 started working on the training task, P3G1 joined their workspaces without asking P4G1; at this point P4G1 said:

"We can both go to more places" —P4G1.

Then they split the workspace and each worked independently.

Figure 30: P3G3 and P4G3 split their workspace after P1G3 and P2G3 did

6.1.5 Overlapping:

One of the issues that participants faced while doing the tasks was overlapping workspaces that occurred twice between subgroups and once within subgroup. This was mainly due to the small size of the table and tracked region relative to the number of participants. However, participants overcame this issue by moving their bodies to move their workspaces. Movement was somewhat influenced by the dimensions of the table. For example, the workspace of P1G3/P2G3 was partially obscured by that of P3G3/P4G3; at that point P1G3/P2G3, who were working on the long side of the table, moved to the right. On the other hand, P3G2/P4G2, who were working on the short side of the table, asked P1G2/P2G2 to move their workspace:

"We cannot see ourselves, can you guys shift that way"-P4G2, "yeah go that way"-P3G2.

We can see that when participants had more space, they moved without interrupting others (as with G3); but they asked others to move when they did not have space to move themselves (as with G2).

Figure 31: Overlapping between subgroups' workspaces

6.1.6 Other Behaviors:

When sharing between pairs, we expected to see participants move to the other side of the table or ask the other subgroup to follow them as they navigated the website to show what they want to share. This kind of sharing was the sole motivator in the tasks for movement to another side of the table. What happened in all cases, however, is that each pair showed what they wanted to share in their workspace and started to explain about it and the other pair just watched from their position and sometimes tilted their heads to see better. In one instance, P2G1 asked P3G1 and P4G1 if they could come next to them to show what they wanted to share, but this did not transpire. Moving to the other side of the table did not happen perhaps because of the size of the table.

We noticed that participants tried to scroll by dragging the content of the workspace, which can be done only via the scrollbar with the UI toolkit we were using. The position of the scrollbar in the shared workspace influenced behavior, but strategies differed between groups. P2G2 asked her partner P1G2 to scroll because she was closer to the scrollbar. On the other hand, P1G1 and P2G1 switched positions to allow the driver (P2G1) to reach the scrollbar. In G1 P2G1 was leading the interaction in his pair and participants switched positions instead of switching roles. But in G2, P2G2 was trying to show something to P3G2 and P4G2 but could not reach the scrollbar and asked P1G2 to interact and follow her instructions.

Another behavior that we observed across groups is leaving the tracked region, to start as new user, in order to overcome technical issues (e.g. losing track of users and mixing users to one person). This would cause the participant to lose his/her position on the website, so was only used when necessary. For example:

"Oh no, we disappeared"- P1G3
"Do you want to step away"-P2G3
"Yeah let's just go back"-P1G3.

6.1.7 Detection Accuracy:

In terms of detection accuracy, the system had two detection issues. First, for users who stand in the far corner of the short side of the table the system misplaced their workspaces twice (with P4G2 and P4G3). We believe this was caused due to the noise data the camera captures at that corner (because the camera had curved corners due to using Kinect lens to zoom out in order to have wider view). The second issue was merging of two users into one user when users stood shoulder to shoulder, a discussion of this issue is in section 3.2.3 of Chapter 3.

Table 2 shows a summary of user's behaviors; these behaviors were performed to overcome issues participants faced while completing tasks, collaborate with their partner, and use features of our system. The table also shows design implication for each behavior in addition to the number of time each behavior occurred as well as in how many groups it was repeated.

Behavior	Design Implication	Number of groups	Number of times for all groups
Moving workspace by hands	Users should have control over system's control	3	6
Back away to make room for partner to move the workspace	Users should have control over system's control	1	1
Switching positions to reach scroll bar	Design of the interface affected the way user interacting with the system	1	1
Switching positions to move workspace	Users should have control over system's control	2	2
Moving to avoid overlapping	The system should not allow for overlapping	2	2
Asking other group to move to avoid overlapping	Users should have control over system's control	1	1
Join workspaces	Users prefer to work on joined workspace even when they can work independently	3	15
Split workspace	Some users prefer to work independently because of the type of the task and some others want to save time	2	3
Work on small workspaces	Participants chose this option to work in parallel	3	6
Trying to increase workspace's size manually	Users should have control over system's control	1	1
Interacting with partner's workspace	Even when working independently, users still collaborate	1	1
Explaining task to partner while working independently	Even when working independently, users still collaborate	1	1
Sharing between subgroups from their positions	Users need to have manual control to move and rotate their workspaces	3	6
Keep track of other subgroup work	Users try to learn what to do from others	2	4
Asking partner to scroll because cannot reach	The interface need to be designed in a way that all users can interact with	1	1
Scrolling by dragging the content	The system should provide users with natural interaction techniques	3	7

Table 2: Summary of users' behaviors

6.2 Questionnaire's Data:

All of our participants agreed that adapting the size of the workspace to the size of the group allows to better intraction while completing collaborative work. The majiroty of them also understood how the system responded to each behavior. However, we had few times where the system did not respond acuratly due to technical issue participants faced while interacting with the system.

	Strongly agree	Somewhat agree	Neutral	Somewhat disagree	Strongly disagree
Adapting work region to group's size lead to better intraction	10	1	0	0	0
Understood system's responces	1	9	0	1	0
The system provides proper interface changes	0	5	3	3	0

Table 3: Rating scale questions

	Yes	No	Do not know
Did you notice the system recognized user's movments around the table?	11	0	0
Did the system respond in appropriate way by making the workspace follow the user?	8	3	0
Did you notice the system reconized two or more users coming together and create group?	11	0	0
Did the system respond in appropriate way by adjusting the size of the workspace to the size of the group?	11	0	0
Did you notice the system reconized one or more users leaving the group?	6	3	2
Did the system respond in appropriate way by creating workspaces for those who left the group?	4	1	6

Table 4: Yes and no questions

6.3 Issues While Using The System:

While participants interacting with the system, we ran into some technical issues:

- Losing workspace: this occurred for a number of reasons: first, two users stood shoulder by shoulder where the tracking system mixed and saw them as one user. At this point users ended up with one small workspace. Second, when users leaned down toward the display, the tracking system lost track of them because they left the depth threshold. At this point their workspaces were removed from the display. Third, in the case of joined workspaces, when the owner of the workspace left the tracked region accidently, the workspace was removed from the display and caused the group to start again.
- Positioning joined workspace: when two users joined their workspaces the system would place the joined workspace in the middle where both users would see and interact with it. During the interaction, the system misplaced the workspace (shifted to the right or the left a bit) which made users try to move it with their hand.
- Overlapping: since we had a limited tracked region (only two sides of the table), overlapping occurred between subgroups a number of times that made participants act in a different way to avoid that. To solve that we came up with a technique that prevent overlapping as will be discussed in section 6.3.2.

6.4 Focus Group Post-Task Discussion:

6.3.1 Alternative Usages:

During the discussion participants suggested a number of interesting scenarios where ProximityTable could be used. First, using ProximityTable on a kitchen island where instructions follows the chef as s/he moves around. Second, instead of switching laptops with the projector at supervision group meetings, each student has his/her presentation in his/her own workspace and when they move to the front to present, their work might be automatically shown on the projector and when they move back it moves form the projector. Third, it would be used by couple of student and advisor at the registrar's office, where students would figure out there registration or their program courses. Finally, it also can be used in gaming such as hand twister.

6.3.2 Improvements For The Prototype Application:

The first suggested addition to the current version is giving users more manual control (include moving, rotating, and resizing workspaces by hands) over system control (e.g. moving workspaces as users move). Users will have the option to enable and disable the manual control through a switch in each workspace. When manual control is enabled, there will be a maximum size of the workspace according to the number of workspaces at the table, to make sure no one will take more space while there are others interacting. Users also will be given more options as responses to proxemics events (e.g. joining or splitting workspaces, which workspace to keep, overlap both workspaces with taps on top to switch between them, and drag one tap out of the workspace to split them).

The second suggested addition is when a new user comes to the table a bubble will be displayed asking if s/he wants to interact, if the user taps on it a new workspace will be created. Currently, our prototype application notifies users about onlookers and asks them if they want to increase the size of workspace or ignore them. This might be improved by shifting the workspace a bit up when there are more than one onlooker trying to look over the user's shoulders, to allow onlookers to see. The third suggestion is to avoid the overlapping issue, so that when edges of workspaces touch, they will not move. If they are touched because a user is trying to pass behind another one, the area will stop moving and it will jump to the other side when its owner passes that user.

There are some other interesting suggestions that might be useful in any prototype based on the type of environment that it will be used in. First, using techniques such as RFID, touch ID, and signing in to keep track of users even after they leave the tracked region and to retrieve their stored work. Second, when joining workspaces, all documents from both users become in one big workspace; or the work will be merged into one element (e.g. document) after each user completes different aspects of the task. In the case of splitting, the big workspace will be duplicated into two smaller workspaces, and then users can choose what to keep and what to close. The prototype also might have a button that gives users the option to keep their workspaces even after they leave the table (e.g. for a coffee or phone call).

6.5 Summary Of The Results:

Our prototype application was used by a small number of participants to complete two specific tasks in order to evaluate proxemics events that ProximityTable generates. Our settings had a limitation of the size of tracked region relative to the size of the table and number of participants in each group. This section summarizes our findings of using the implemented prototype application within this limited setting according to our research questions. These findings need to further exploration by using ProximityTable in different context in order understand the benefit of proxemics across different tabletop application.

1) *What user behaviors should trigger a response from the interactive tabletop?* ProximityTable currently recognizes seven behaviors and creates event for each: approaching the table, leaving the table, moving around the table, moving to different side of the table, grouping, breaking up groups, and recognizing onlookers. Recognizing these behaviors meant to be used to support collaborative work of multiple individuals and groups around a tabletop display (e.g. different styles of task coupling [1, 17]). Using ProximityTable framework, a prototype application was implemented to test these behaviors (as discussed in Chapter 4). Our participants used the implemented prototype application and during the discussion they expressed their opinions about its features. All of our participants agreed that ProximityTable should recognize and respond to these behaviors except recognizing onlookers; for recognizing onlookers, only two out of 12 participants think that it is not important and it should not be included in

ProximityTable. Even when we gave them a number of possible responses, they did not change their opinions.

2) *Under what circumstances will users prefer automatic adaptation, symbiotic user-system agency, or direct user control?*

The current prototype application gives users a bit of control over system's control that is by allowing them to choose when to start/stop moving the workspace, to join workspaces, and to increase the workspace when there is a bystander. From our study we learned that it is not enough to have only system's control and users need to have a switch between user and system's control. For example, the workspace currently moves only by the system and users can only choose when to start/stop moving; but what we learned is that when users stop the system's control of moving the workspace, users should be able to move them by their hands.

3) *What kind of interface changes will best communicate group formation and dispersal, and the transition between active user and bystander?*

The current prototype application responds to ProximityTable grouping event by notifying users that they are in grouping threshold and give them the chance to join their workspaces, which our participants agreed about. On the other hand, they did not like the system to control the response for splitting event, where it waits for 5 second then splits the workspace. Our participants would like to have the control similar to joining option. In addition, ten out of twelve participants agreed that they system should notify users about bystanders and leave it to the main user to allow the bystander to involve in the interaction or not, which the implemented prototype do as a response to ProximityTable recognizing onlookers event.

4) *How effective is it to dynamically adapt group work regions according to group size when more than one group is using the interactive table?*

In a similar to Klinkhammer et al. in [2] where they provide a workspace for each user, our main concept is to provide each group with a private workspace that matches the size of the group. When participants used the prototype application we observed that 11 out 12 join decision were made for single activity tasks and 4 out of 6 join decision for two activities task; also it is mentioned by one participant that she like the workspace when it is bigger. We believe having multiple groups with workspaces matches the size of each group will be useful in situations like classrooms [28].

Chapter 7: Discussion and future work

This chapter will discuss our findings and show how are they related to our objectives (section 7.1). It will also discuss the future work of ProximityTable as well as some usage-based recommendations.

7.1 Discussion:

While implementing our framework, we were aiming to provide developers with a set of proxemics events according to individual's position relative to the tabletop and/or to another individual. Based on the data we receive from DT-DT, we generated seven proxemics events: approaching, leaving, moving, switch orientation, grouping, splitting, and recognizing onlookers. Each of these events can generate any response based on the type of application, but we designed a response to each event in order to evaluate how these events can support collaborative work around tabletop displays. When designing these events and responses, we considered the use of both meanings of space (territories and personal spaces) [39]. We also considered the way people mark their territories in public spaces through the use of their bodies and personal spaces [42]. In addition, we considered the use of four out of five dimensions of proxemics for ubicomp that Greenberg et al. described in [15]. In our model we assigned each user with a uniqe ID and use the distance between users and display, and users themselves as well as their movements to generate proxemics events. We also use the location dimention by determining the position and dimensions of the display.

To evaluate these responses and to explore how to use these events to support collaborative work around tabletop displays, a prototype application was implemented using ProximityTable framework. First, we wanted to explore what user behaviors should trigger a response form the interactive display. Five of the current recognized behaviors (approach the table, leave the table, move around the table, form a group, and break the group) were evaluated through three focus groups as described in chapter 5 and participants agreed that ProximityTable should detect and respond to these behaviors. Recognizing onlookers and moving to the other side of the table are additional behaviors that ProximityTable can detect and respond to, but they were not evaluated. During the discussion ten out of twelve participants agreed to recognize onlookers' behaviors and notify users.

Marshall et al. designed TouristPlanner [18] (discussed in chapter 2) in a way that it can be used by up to four users as one group. They found that in some cases groups are joined by complete strangers. To avoid such situations, our prototype application allows multiple groups and individuals to interact with the display simultaneously by creating private workspaces for each. In addition, Marshall et al. [18] found that some people used only one side of the table even if the rest was available to use. One reason of working on one side is that they prefer to have a joint focus; our prototype supports both scenarios by allowing users to interact as a group or individuals through merging/splitting their workspaces. The second reason is that some people did not know that they can use the table at the same time. This shows us how important proxemics is to tabletop interaction; because if the system were able to detect users, it might notify them that there is a chance to work in different parts of the table. In Klinkhammer et al.'s work in [2], when two users come close to each other the system will wait for 15 seconds then remove one workspace and keep the other one as it is. In the same case our prototype asks users if they want to merge their workspaces and if they choose to, it will remove one workspace and increase the size of the remaining one to match the size of the group. In our study, participants agreed that the size of the workspace should match the size of the group.

In terms of group formation, Marshall et al. [18] stated that it is rare for group members to arrive at and leave the display at the same time. Azad et al. in [19] also stated that group formation sometimes changes over time, where there are "active user, active observer, and passive observer" [19]. This brings us to discuss bystanders since the group formation might change because of them. Klinkhammer et al. in [2] stated that "Out of the 968 user sessions, 257 users were bystanders who did not interact with the system at all (26.55%)" [2]. There are a number of the rest of users who were bystanders and became actual users. This tells us that in some tabletop applications bystanders sometimes want to interact but the system does not allow them due to a limitation in the number of workspaces. Our prototype recognizes bystanders, which is used to notify actual users about their presence; actual users then can choose to increase the workspace to allow a bystander to become involved in the interaction or they can ignore their presence and continue their work. In addition, if we enabled the orientation detection feature in DT-DT, we might be able to detect disengaged users and control bystanders' responses based on their position and orientation.

In terms of interface changes, all participants agreed that ProximityTable responds appropriately to users' behaviors, but they also suggested a number of responses that they could be useful in different applications (discussed in section 6.3.2 Improvements for the prototype application in Chapter 6). However, participants had some issues with the way that the system carried out these responses. For example, participants wanted the option to split workspaces but they preferred to have a controller (e.g. button) instead of waiting for 5 seconds. This leads to our third research question: would users prefer automatic adaptation, symbiotic user-system agency, or direct user control? During the discussion session participants stated that they prefer to have manual control over system control. They want the system to detect users' behaviors and then ask users if they want to perform the response (e.g. join workspaces), so they will have the control over the system. This shows how important it is to integrate both proxemics events and UI events when using proxemics for tabletops (e.g. in our prototype the join decision requires two events: "grouping event", which is a proxemics event, and "touch down event", which is a UI event). Another example of user control is having a switch between user and system's control, where the system will move the workspace according to user's movements but the user should be able to move the workspace by hand when s/he switched to user control.

From our research we learn that using a top-down tracker provides information not only about users but also bystanders, which will enhance the process of supporting collaboration work around tabletop displays. Even we had a limitation in terms of the size of the tracked region in our currant settings, we believe that using a top-down tracker provides more proxemics data, while using low cost and easy to deploy technology, to support collaborative work but it needs to more investigation.

We also found that it is important to provide users at least with a minimum control over system control. In our current prototype application, we expected that automatic control would be enough for users to interact with the interface (similar to Klinkhammer et al.'s approach in [2]); but we found that all of our participants preferred to have manual control over system's control (switch between user and system's control). We believe providing such control will prevent users from acting unnaturally (e.g. in some cases users leaned left or right to move the workspace, which would not happened if they have that control). In addition, we learned that providing manual control does not only mean enable/disable system's control (e.g. enable/disable workspace movements in our prototype) but also allow users to directly interact with objects (e.g. move the workspace by hands).

We had many cases of overlapping where participants acted differently to overcome this issue. Once they moved by themselves to avoid overlapping because they were on the long side of the table and their workspace was below the other one. The second time, participants asked the other pair to move because they were on the short side of the table. This point might be taken into account while designing such application by making the workspace on the long side always under the one on the short side.

We believe ProximityTable provide developers with an important set of proxemics events that might be useful for different types of applications. We also believe that approaching and leaving events are fundamental proxemics events that need to be used in any tabletop application because they allow the application to know about the presence and absence of users. For example, a situation where users do not know that the system can be used by multiple individuals at the same time (e.g. similar to the situation we discussed earlier of Marshall et al.'s work [18]) can be avoided when they system know about users' presence.

In terms of having multiple groups in a single display, from our observations we believe having multiple groups in a single display shows a good promise for collaboration around tabletop display, even when we had some issues with our currant settings, we believe this might be useful in different domains (e.g. classroom environment in [28]). In addition, having multiple groups at single display or single user with a group of users, we believe adapting the size of the workspace according to group's size will allow for better interaction; as 11 out 12 join decision were made for single activity tasks and 4 out of 6 join decision for two activities task.

There were impacts of tasks, table size, and the size of tracked region on our evaluation. Entering and leaving were not really used and recognizing bystanders was not used at all because tasks require users to approach the table and stay until the end of the sessions; so, participants came and left the table at once. The table size and the limited tracked region caused overlapping between workspaces and did not allow participant to move around while sharing with other pairs, which limited the uses of moving and changing orientation features.

In our research we conducted an exploratory study and we had a small number of participants who did a small number of tasks with a specific prototype and web application. We also had a small tracked region relative to number of participants in each group and to the size of the table. This limits our results of testing the benefits of using proxemics events and their responses. In our results we presented some ideas and pointers for further exploration in proxemics-aware systems. Such events need to be explored more by using them in different environments (e.g. classrooms) to perform different types of tasks (e.g. work on a group project) by a large number of participants. Using such systems in different contexts might generate different behaviors to be recognized and show how different behaviors might be more important than other based on the context.

7.2 Future Work:

Based on our experience of implementing ProximityTable framework and the prototype applications and testing the prototype through focus groups, we came up with a number of interesting questions that might help to support and improve collaborative work around tabletop display.

In our current settings, the display is an entity and we used only one zone around the table as a personal space of it due to the limitation of the tracked region. What would be interesting is to have wider tracked region where we can divide the space around the display to two or three different spaces (e.g. similar to the work of Vogel and Balakrishnan [12]). We would like to know what kind of responses might occur with such division when there is a transition between different zones. For example, when a user enters the personal space of the table, s/he will be notified about the openness of the table; and if enters the intimate space of the table, a new workspace will be created. Another example would be recognizing a person as a bystander when s/he enters the intimate space of another user and still in the personal space of the table. Having a wider tracked region also allows us to explore some other complicated proxemics scenarios. For example, what if we have User C, who does not have a workspace, standing in the intimate space of User B, who is a bystander of User A. In such situation do we recognize User C as a bystander of User A? What if the group formation changed and User B and User C switched positions?

Another interesting point is recognizing the orientation of users according to other users and to the display. For example, in Azad et al.'s work [19], they observed that in some situations a group member is facing other members and not paying any attention to the display. So, how should the system response to such situations where we have User A facing User B and User B is standing on the other side of the table? What if we have a situation where User A facing user B and they both stand at the same side of the table? To what extend absolute orientation can be useful for collaborative work around tabletops?

It will be also interesting to consider security/privacy as an additional feature the framework can provide. If we integrate RFID tags with the existing framework as additional source of information to secure the access to existing filesin the system. So, when a user reach the table s/he has to swap RFID tag before s/he gets the access to the system. Another way is to ask users to access through the use of user name and password.

Chapter 8: Conclusion

This dissertation discussed ProximityTable framework that is a tabletop interactive system that uses a top-down tracker to track users around the display. Based on this tracking data it will generate a number of proxemics events that can be used by developers to generate application-based responses. It also discussed in detail the architecture of ProximityTable framework. In addition, it described ProximityTable application that generates responses based on proxemics events. What is more, it described the user study that was conducted to evaluate ProximityTable and stated its research questions. It also discussed the evaluation of each feature in ProximityTable. From that evaluation we found a number of improvements to ProximityTable as stated in the future work in chapter 7. These improvements are for existing recognized behaviors (e.g. joining and splitting, additional behaviors (e.g. recognizing bystanders), as well as interface changes according to these behaviors. we also found that users preferred to work collaboratively on one big workspace even when they have the chance to work on a subtask independently. We also found that users preferred to have manual control that is supported by the system, where the system detects the behavior and asks user's permission before doing any response.

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Appendix A – Recruitment Notice

We are recruiting participants to take part in a research study examining how behavior around interactive tabletop displays can be reflected in the tabletop interface itself, to better support work. We are looking for participants who are part of the wider Dalhousie University community, including students, staff/faculty, and friends. We are seeking groups of people (preferably four or larger) who are studying in the same major or working in the same department. Interested individuals and groups less than 4 are encouraged to contact us as well; we will work to pair you with suitable collaborators.

The study will be conducted in the GEM Lab, Mona Campbell Building, and will take about 1 hour 15 minutes minutes to complete. You will first meet with a researcher to go over the study details, and give consent to participate in the study. You will perform a number of tasks using the interactive tabletop display that involve coordinating with other participants, and your interactions will be video-taped. After this you will discuss and explore interface improvements and alternatives as a group. Compensation is a $20 Amazon gift card for each participant.

If you are interested in participating, please contact Mohammed Alnusayri (alnusayr @cs.dal.ca).

Appendix B – Informed Consent

Examining the impact of tabletop interfaces that respond to body position and orientation.

Principal Investigators: Mohammed Alnusayri, Faculty of Computer Science
Dr. Derek Reilly, Faculty of Computer Science
Elham Alghamdi, Faculty of Computer Science
Mohammed Sembawa, Faculty of Computer Science
Majid Nasirinejad, Faculty of Computer Science

Contact Person: **Mohammed Alnusayri, Faculty of Computer Science, alnusayr@cs.dal.ca**

We invite you to take part in a research study being conducted by Mohammed Alnusayri at Dalhousie University. Your participation in this study is voluntary and you may withdraw from the study at any time. Your academic (or employment) performance evaluation will not be affected by whether or not you participate. To be eligible to participate in the study, you must be a member of group of four who are studying in the same major or working in the same department and you are 18 or older. The study is described below. Participating in the study might not benefit you, but we might learn things that will benefit others. You should discuss any questions you have about this study with Mohammed Alnusayri.

The purpose of the study is to help us learn how behavior around interactive tabletop displays can be reflected in the tabletop interface itself, to better support work. You will be asked to participate in an approximately 75 minute-long study where you will perform a set of tasks using the interactive tabletop, and then reflect on the experience in a group discussion. You and three other participants will be using the tabletop at the same time, and your interactions will be video-taped.

You will be compensated with a $20 Amazon gift card for participating in the study; you can withdraw from the study at any time without consequence. A researcher is always available over the study period by email or to meet in person to answer any questions you may have or address any problems that you may experience with the tasks.

At the beginning of the study, you will meet with an investigator (in the Mona Campbell building). At this initial meeting you will be asked to give consent to do the study. You will be given a general description of the type of tasks we want you to do during the study. After completing tasks, you will be asked to fill out a short questionnaire and then to participate in a discussion session to speak about your experience with using the system. You will be video recorded.

All personal and identifying data will be kept confidential. Anonymity of textual data will be preserved by using pseudonyms (e.g., an ID number) to ensure your confidentiality. Images or videos used in publications or presentations will have faces blurred to provide anonymity. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance to University policy for 5 years post publication.

In the event that you have any difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact Catherine Connors, Director, Office of Research Ethics Administration at Dalhousie University's Office of Human Research Ethics for assistance: phone: (902) 494-1462, email: Catherine.connors@dal.ca.

"*I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction.* ***I understand that being video taped is necessary to participate in the study.*** *I hereby consent to take part in the study. However, I understand that my participation is voluntary and that I am free to withdraw from the study at any time."*

Participant	Researcher
Name: ______________________________	Name: ______________________________
Signature: ___________________________	Signature: ___________________________
Date: __________________________________	Date: __________________________________

Please select **one** of the options below:

☐ "*I agree to let you directly quote any comments or statements made in any written reports without viewing the quotes prior to their use and I understand that the anonymity of textual data will be preserved by using pseudonyms.*"

Participant	Researcher
Name: ______________________________	Name: ______________________________
Signature: ___________________________	Signature: ___________________________
Date: ____________________________	***Date:*** ______________________________

Or

☐ *"I want to read direct quotes prior to their use in reports and I understand that the anonymity of textual data will be preserved by using pseudonyms."*
[if this option is chosen, please include a contact email address: ___________________________]

Participant	Researcher
Name: ______________________________	Name: ______________________________
Signature: ___________________________	Signature: ___________________________
Date: ____________________________	***Date:*** ______________________________

If you are interested in seeing the results of this study, please check below and provide your email address. We will contact you with publication details that describe the results.

☐ *"I would like to be notified by email when results are available via a publication."*

[if this option is chosen, please include a contact email address: ___________________________]

Appendix C1 – Training Task (A)

Please follow the following path to fill out the schedule:

Collection>Explore the collection>Dutch history>

Period	Highlights of this section
1650-1715	

Appendix C2 – Training Task (B)

Please follow the following path to fill out the schedule:

Collection>Explore the collection>Dutch history>

Period	Highlights of this section
1810-1848	

Appendix D1 – First Task (Activity A)

You will work as a group of two members.
Part A:

1- First member: you are interested in military history. Find two types of war equipment used historically by the Dutch, and find specific examples of each type as well as they year they were made.

Suggested path to start with:
Collection > Explore the collection > Works of art

<table>
<tr><th>History of</th><th>Type of equipment</th><th>Examples</th><th>Year</th></tr>
<tr><td rowspan="4">War equipment</td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

Part B:
Figure out a route through the museum that will allow you to visit the museum together and see each of the items you have identified.

Appendix D2 – First Task (Activity B)

You will work as a group of two members.
Part A:

1- Second member: you are interested in 19th century Dutch paintings. Find two artists who lived in that century. For each artist give details (title and year) about two of their paintings that you found interesting.

Suggested path to start with:
Collection > Explore the collection > Artists

<table>
<tr><th>History of</th><th>Names of artists</th><th>Examples</th><th>Year</th></tr>
<tr><td rowspan="4">19 century paintings</td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

Part B:
Figure out a route through the museum that will allow you to visit the museum together and see each of the items you have identified.

Appendix E – Second Task

You will work as a group of two members: you are both responsible to plan a trip for school kids to a Dutch museum. Peruse the museum’s website and choose five sections to visit. For each section, state what you think kids will learn from the section, and give two examples of items that you would want to highlight in this section.

Tip: A list of sections can be found following this path on the website:
plan your visit> general information> building and presentation

Section to visit	What do you expect to learn in this section	Examples

Appendix F – Questionnaire

1- Interface responses to my movements around the table should be:
   a. Automatically controlled by the system.
   b. Supported by the system, but managed by me.
   c. Completely under my control.

Please explain:

………………………………………………………………………………………………
………………………………………………………………………………………………

2- Adapting the size of the work region according to group size allows for better interaction.	1 Strongly agree	2 Somewhat agree	3 Natural	4 Somewhat disagree	5 Strongly disagree
3- I understood how the system was responding to my behaviors around the table.	1 Strongly agree	2 Somewhat agree	3 Natural	4 Somewhat disagree	5 Strongly disagree
4- The system provides proper interface changes based on user behaviors.	1 Strongly agree	2 Somewhat agree	3 Natural	4 Somewhat disagree	5 Strongly disagree

Yes and No questions			
5- Did you notice the system recognized user's movements around the table?	1 Yes	2 No	3 Don't know
6- Did the system respond in appropriate way by making the workspace follow the user?	1 Yes	2 No	3 Don't know
7- Did you notice the system recognized two or more users coming together and create a group?	1 Yes	2 No	3 Don't know
8- Did the system respond in appropriate way by adjusting the size of the workspace to the size of the group?	1 Yes	2 No	3 Don't know
9- Did you notice the system recognized one or more users leaving the group?	1 Yes	2 No	3 Don't know
10- Did the system respond in appropriate way by creating new areas for those who leave the group?	1 Yes	2 No	3 Don't know

11- Is there any additional user behavior you think should be recognized by the system? If yes, please describe.

………………………………………………………………………………………………
………………………………………………………………………………………………

12- Are there any interface changes you think should be included in the system? If yes, state them please.

………………………………………………………………………………………………
………………………………………………………………………………………………

Appendix G – Focus Group Outline

During the discussion video clips of the interface and its content as well as user will be presented on a wall display, as it might be needed by participants to explain their opinions.

In the beginning we will discuss the following questions:

1- What do you like about joining a group and splitting from group?
2- What do you dislike about joining a group and splitting from group?
3- What do you like about making workspace follow the user?
4- What do you dis like about making workspace follow the user?
5- What do you like about increasing the size of the contents on the workspace when there is a bystander looking to the same contents?
6- What do you dislike about increasing the size of the contents on the workspace when there is a bystander looking to the same contents?
7- Do you think adapting allocated group work regions according to group size allows to better interaction? Why or why not?
8- What limitations can you see in the system?
9- In which ways do you think the system can be improved?

After we are done with the questions, participants will be given 10 minutes to think about the following questions (brainstorm alternative usages):

If you are going to use this system in your field of study or in your work department, what kind of tasks will you perform on this system?

Appendix H – Social Sciences & Humanities Research Ethics Board Letter of Approval

July 21, 2014

Mr Mohammed Alnusayri
Computer Science\Computer Science

Dear Mohammed,

REB #: 2014-3250
Project Title: Examining the Impact of Tabletop Interfaces That Respond to Body Position and Orientation

Effective Date: July 21, 2014
Expiry Date: July 21, 2015

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans. This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Valerie Trifts, Chair