ABSTRACT
A paradigm shift from single-user computing to face-to-face communication enhanced by computer interfaces is taking place. This shift asks for a new kind of multi-user, multi-touch interaction and that leads to the use of new touches and gestures. I present a research paper that will give a state of the art in multi-touch, multi-user tabletop development, focused on enhancing collaborative group work around tabletops with the use of gestures. I will discuss what makes a good gesture and in which direction future development of interaction methods and gestures should proceed.

Keywords
multi-touch, multi-user, tabletop, gestures, collaborative work, group meetings.

1. INTRODUCTION
Computers have been used as single-user devices for a long time. Human-computer interaction was the main paradigm and keyboard and mouse were the standard input devices. With new technology, we see some changes taking place. First, we see that more and more multi-user input is possible, meaning that more than one person can interact with a device at the same time. On the other hand, we see a change from human-computer interaction to computer-mediated human-to-human interaction [1]. Computer devices are increasingly assisting with face-to-face communication. People are often gathering around tables to do collaborative work, such as having a meeting or holding a brainstorm session. In the past, most relevant documents are printed out and handed out to every person. One person might take notes and create minutes on a laptop, but that is a single-user task. Mainly paper and pencil are used to take personal notes, remember comments, or show others with a picture what you mean.

With the use of multi-user, multi-touch tabletops, the work that has to be done might be done more efficient and structured. The documents needed for the work that has to be done are available digitally on the tabletops, giving lots of new possibilities.

Tabletops might increase group experience by creating a more efficient atmosphere to work with, as mentioned by Falcon et al. [3] and Scott et al. [4]. This improved atmosphere might improve the results of collaborative work.

Also, other input methods are introduced. Objects and data can be added, organized and deleted with the use of one’s fingers and hands, instead of traditional keyboard and mouse. This is called the shift from clicks to touches, by Shen [1]. A gesture is a combination of one or more touches, performed by one or more users.

The question arises in what way all these touches and gestures used for interacting with the tabletop enhance face-to-face communication while doing collaborative work.

2. PREVIOUS WORK
2.1 Technology
This section shortly describes what development has been done in the last years regarding multi-touch, multi-user tabletops to give the reader a better idea of the field that is being discussed.

Traditional tabletop workspaces have long been considered the ideal collaboration environments for small groups and single-user computing was the main paradigm for a long time. With new technology researches started to develop digital tabletops. As the development of tabletop systems becomes easier through special purpose tabletop hardware, for example the DiamondSpin [6] tabletop in 2001, and software toolkits such as the DiamondSpin toolkit [11] more complex tablet interfaces are being created. Also other tabletop devices with different toolkits are being developed after 2001.

With a multi-touch, multi-user tabletop, such as the DiamondTouch, several different people can touch the display simultaneously without interfering with each other. The display is able to distinguish different users by using modulated electronic fields which are capacitive coupled through the users. Every touch-point at the display has the charge from a specific user and enables the display to separate actions between users. This gives a broad new set of possibilities for collaborative group work around tables as documents are now available digitally.

2.2 Research
In previous research, we see that multi-user, multi-touch tabletops can indeed improve face-to-face communication. I will give some examples. Ideas generated with a brainstorm utility [2] were of higher quality than a classic paper-based brainstorm session. The number of ideas generated was about the same. Hilliges et al. [2] generated a list of guidelines and design goals for future work.

Scott et al. [4] mention guidelines for further development, which they base on critical analysis of many years of experience with tabletops. I will use these guidelines as criteria when researching and comparing gestures and touches.

One of the benefits of the use of these multi-touch tabletops is mentioned by Rogers et al. [5]: the ability to still be able to talk to each other, as with classic face-to-face communication.
This contrasts with the development into remote meetings assisted by computers. The AMIDA project [15], Augmented Multi-party Interaction with Distant Access, shows promising results in the area of remote meetings. These meetings can be very useful on their own. Still, face-to-face communication is a more natural way of communicating with each other and people will continue to have face-to-face meetings. Therefore, research should not only be focused on remote meetings but surely also face-to-face meetings should be taken seriously.

As explained by Tse et al. [9], the combination of speech and gestures is an efficient and natural way of interacting, compared to speech-only interaction. Some of the benefits of this combination are: the ability to explain what you are pointing at with the help of *deictic references* (speech terms like ‘this’ and ‘that’ whose meanings are qualified by spatial gestures such as pointing to a location), a more efficient way of using speech with less errors, the ability to explain what you are doing with *alouds* (high level spoken utterances), *gaze awareness* (people monitor the gaze of other collaborators to see what they are doing) and the ability to do work simultaneously. For example, Tang [12] observed groups of three or four people together performing a conceptual design task, and approximately 50-70% of people’s activities around the tabletop involved simultaneous access to the workspace by more than one person [9]. The above benefits do not only apply on tabletops, but also on other interfaces used for collaborative group work.

Kruger et al. [17] mention the problem of orientation. People stand at different positions around the table and will be viewing the contents from different angles. The authors investigated tabletop interaction with respect to the coordinative, communicative and comprehensive roles of orientation and concluded the following for future design. Free rotation should be supported, rotation techniques must be lightweight, user-positioned items should keep their orientation, rotation actions should be clear to other users and automatic orientation should be easily overridden by users. Koster [7] investigated two interesting rotation and translation techniques, *RNT* and *Corner*, which showed conflicting results in earlier studies. The reason for conflicting results was not discovered, but *RNT* was the fastest technique under all conditions. Forlines et al. [8] also investigated the problems of rotation techniques, and assumed larger documents form a bigger problem for rotation and users should be encouraged to use the center of an item to start rotating it.

We also see that current interaction techniques not fully exploit the increased input bandwidth that multi-touch input gives us. Wu et al. [14] present a variety of multi-finger and whole hand gestural interaction techniques, using an application they call *RoomPlanner*. They categorize interaction techniques in four categories: single finger, two fingers, single handed and two handed.

### 3. PROBLEM STATEMENT

Current research shows us that multi-touch, multi-user tabletops are able to increase the performance of collaborative group work and improve face-to-face communication. What is not so clear is in what way interaction on such tabletops should take place, and which gestures and touches increase performance and which might hinder performance. So the question is not whether tabletops are able to increase performance. As explained before, literature shows the answer to this question is a sure yes.

The research question formulating the problem is as follows:

- Which gestures improve collaborative work on multi-touch, multi-user tabletops?

### 4. METHODOLOGY

Before going into detail, I will describe the used methodology. I investigated gestures used on multi-user, multi-touch tabletops and compared the results of different work in the field. Based on this research I created a set of criteria to compare the usefulness of gestures. I will present the gestures, explain how they work and discuss their usefulness based on the criteria. I will use a categorization based on Wu et al. [14]. Finally, I conclude which gestures are useful for interacting with tabletops while doing collaborative group work.

### 5. DEFINITIONS

In this section, I will clarify what should be thought of when talking about multi-touch, multi-user tables and gestures.

#### 5.1 Multi-touch, multi-user table

Before I discuss gestures used for interaction with multi-touch, multi-user tables, the definition of such a table is clarified.

A multi-touch, multi-user table is a digital tabletop device with a display that can be touched directly to interact with it. Multiple input methods (i.e. a finger, a hand or a pencil) can be used directly on different places on the tabletop, making it *multi-touch*.

Also, multiple users can interact with the table at the same time, making it *multi-user*. These tabletops ask for a new kind of interaction, with the use of users’ bare fingers, instead of traditional mouse and keyboard. Users perform touches and gestures instead of clicks. Because users can interact with the table simultaneously it is important to investigate what makes a good gesture.

#### 5.2 Gesture

I suggest a definition for gestures, because the word is used a lot in literature but it’s meaning might be ambiguous. A gesture is a touch, with a pencil, a finger, a hand of one or more users, interacting with a tabletop device. One finger might be used, two or more fingers, two hands together, or even the fingers and hands of a whole group of people. Also other input methods are possible: arms, elbows or even a nose of a person. While touching the interface, users might move their fingers or hands to perform the gesture. The gesture ends when the user releases his fingers, when some time has passed so the system knows the gesture has come to an end. It is also possible that a gesture is finished when a specific mark or form has been created.

### 6. CRITERIA FOR COMPARING THE USABILITY OF GESTURES

Before comparing gestures used when interacting with a tabletop, I will discuss what makes a good gesture. From different sources I derive criteria for comparing the usability of gestures. I use the guidelines from Scott et al. [4], the research done by Morris et al. [16], and others.

Interaction with a digital tabletop should improve the work that has to be done; meaning the set of gestures used should lead to extended functionality when comparing with the use of classic paper or whiteboards. This is mentioned by Hilliges et al. [2]. Besides extended functionality the gestures are able to perform
The importance of changing the size of a finger and going through gestures is intuitive when users can easily understand and adapt to them. Technology should not hinder the interpersonal interaction. Guideline 6.1 mentions that gestures should be easy to learn and adapt to.

This follows from guideline 6.2, which discusses the appropriate arrangements of users. People feel more comfortable when they can read each other's personal space. Of course, it should be possible to move objects from one side to another side of the tabletop, but in general, the size of the gesture should be taken into account.

7. GESTURES

This section discusses gestures found in literature. Starting from a classic touch of a finger and going through more advanced gestures, the list of criteria mentioned in section 4 will be used to compare and judge the gestures. After that, I hope to answer the research question: Which gestures improve collaborative work on multi-touch, multi-user tabletops?

I categorize gestures as seen before in [14]: single finger, two fingers, single handed and two handed, because I think it is a logical distinction. I also added a section for discussing cooperative gestures.

For each gesture, I will try to clarify the gesture with an icon. These icons might be useful later, for example in manuals for multi-touch, multi-table software. I tried to make these icons as intuitive as possible. After that, I explain the gesture and give some practical applications found in literature. A gesture should be used to perform some task. Some of the tasks might include: pointing, selecting, deselecting, zooming, showing a menu, and many others.

Finally, I shortly discuss the selected criteria for that specific gesture.

7.1 Single finger gestures

7.1.1 Pointing

Gesture: This is the classic mouse-click. The user just touches the tabletop screen on a specific point, with his finger. Further interaction might follow after that. Also, a double click is possible, touching the screen on a specific point two times shortly after each other. We all know this action from the personal computer. Of course, applications might even recognize three or four clicks after each other but one might question how useful that is. This gesture is often called tapping.

Application: A single touch of the table can have thousands of different effects, depending on the application, such as opening a folder, selecting an item, pointing where a creature in a game should walk to [9], and many others.

Criteria: Single clicks match all criteria. An investigation of preferred hand shapes indicates that the index finger is the most intuitive shape to use. It was chosen to be useful for 70% of the tasks.
7.1.2 Dragging

**Gesture:** The user touches the screen with one finger, moves his finger in a line, and then stops. It is optional for this gesture to have to double-click first, before the drag is functional. This might prevent users to accidently move items across the screen when they only want to select.

**Application:** This gesture has a lot of possibilities: dragging and moving objects and items, connecting two items, connecting groups of items, etc...

**Criteria:** This intuitive tool also matches all criteria. One difficulty might arise when users want to move items to the other side of the screen and encounter the personal space of a user working there.

7.1.3 Lasso tool

**Gesture:** The user touches the screen with one finger, moves around some items or data on the screen and stops when he is back where he started. For the system to recognize the lasso some difficulties arise: does the user have to stop exactly where he started, or is there a margin of error. Circling, like in the icon, is the most intuitive way of using the lasso, but of course other shapes are possible.

**Application:** This gesture is useful for selecting a group of items, or grouping them together. This gesture is found in [2], where it is used to combine several items and group them together. These clustering techniques really are an enhancement to classic whiteboards. Whole clusters of items might be moved, deleted or re-arranged.

**Criteria:** The lasso tool is intuitive, orientation is not in issue and the size varies.

7.1.4 Drawing marks

Lots of different gestures are possible with the use of one finger, drawing a mark on the screen. One example is to draw an X.

**Gesture:** The user draws two lines, through each other, making an X.

**Application:** This might have the effect to delete or dissolve the item marked. This was found in [2], where drawing a cross on the border of a cluster causes to dissolve the cluster into single items again. Of course, many more drawings are possible. For example drawing an M might enable the menu or drawing a C might cancel the current action. I think much of these drawings can be very easy to learn and intuitive to the users. But it should stay with easy to learn shapes, like letters.

**Criteria:** Depends on the mark.

7.1.5 Single finger rotation

**Gesture:** Rotation can be achieved by touching the object with one finger and rotating that finger, using friction to turn the paper. Such a technique would require the system to detect finger orientation. One way to do so is to look at where the non-touching fingers are hovering over the surface in relation to the touch point [14].

**Application:** Found in [14] to rotate objects.

**Criteria:** This gesture is a bit more intuitive than the last rotation technique, but it might still cost some time to learn for most users. The result of the rotation is seen directly. Orientation is not an issue, because users sitting on the other side of the table easily follow what the gesture accomplishes.

7.2 Two finger gestures

7.2.1 Two finger rotation

**Gesture:** The first finger determines the centre of rotation, while the second determines the rotation angle. While an object is selected, touching a second finger onto the tabletop initiates the rotation. The change in rotation angle for the object is calculated by the change in angle between the two fingers.

**Application:** Found in [14] to rotate objects in RoomPlanner.

**Criteria:** This gesture is not really easy to learn and might not be intuitive for many users. Its scale is also quite large.

7.2.2 Two finger scaling

**Gesture:** The user touches the screen with two fingers, and by moving them to each other or moving away from each other the system recognizes that and scales the viewport accordingly.

**Application:** Scaling a viewport or zooming in or zooming out, for example when working with maps like Google Earth.

**Criteria:** This gesture is very intuitive, orientation is not an issue and its size varies.

7.3 Single-handed gestures

7.3.1 Flat hand rotation
**Gesture:** A user can temporarily rotate the viewport of the table by placing a hand flat on the table and translating that hand.

**Application:** This was found in [14], where rotating causes to rotate the room in the RoomPlanner.

**Criteria:** A whole flat hand is a big gesture which might block the view of other users. On the other hand, Epps et al. [13] show a spread flat hand is shown to be the most intuitive shape after the index finger, being chosen to be useful in about 21% of the tasks.

7.3.2 **Vertical hand**

**Gesture:** When the side of a hand is placed on the surface of the table oriented such that the contact surface is a vertical line, the user can sweep objects.

**Application:** As seen in RoomPlanner [14], users are able to sweep furniture pieces. As objects make contact with the hand, they are pushed aside and are swept at the same pace as the movement of the hand.

**Criteria:** This gesture parallels the real world action of pushing physical material on a regular tabletop, so the gesture should be very intuitive. But again it is a big gesture to use a whole hand and that might block the view of other users.

7.3.3 **Horizontal hand**

**Gesture:** The side of the hand can be placed on the table such that the contact surface forms a horizontal line. This gesture creates a rectangular box below the hand through which objects within the box display their properties. As the horizontal hand moves, the box follows below it.

**Application:** This gesture was found in RoomPlanner [14].

**Criteria:** It is interesting to note that when a user performs this gesture, the hand acts as a barrier that blocks others from seeing the displayed information. People have to stand up to see behind the barrier, and that violates a rule of privacy.

7.4 **Two-handed gestures**

7.4.1 **Two-handed selection**

**Gesture:** The user uses two hands to make a rectangular selection on the screen.

**Application:** This gesture, for example, can be used to select a group of units a game (Warcraf III, as explained in [9]) or just a set of items.

**Criteria:** This gesture is very intuitive, but it easily gets too large because users might want to select all items available or two items in different corners.

7.4.2 **Two corner-shaped hands**

**Gesture:** Two corner-shaped hands can be used to create a rectangular shape.

**Application:** The selected shape is the editing plane, as seen in [14], which copies a portion of the shared room layout in order for users to individually work on sections of the room.

The initial dimensions of the editing plane are defined as soon as the corner-shaped hands touch the surface. The horizontal distance between the hands defines the initial width of the editing region, and the length of the palm defines its height. The width of the box can be modified by moving the hands horizontally apart, but currently no method is in place to allow for modifying its height. All furniture pieces located within this region are copied onto the editing plane.

**Criteria:** This gesture is not that intuitive, might be hard to learn and is not small in size. Also, orientation might become a problem.

7.5 **Cooperative gestures**

Besides the four categories of gestures for use by a single user, with multi-user technology people cannot only perform single-user actions at the same time, it is now also possible to perform cooperative gestures together. This is called cooperative gesturing by Morris et al. [16]. The authors describe the CollabDraw software which accepts single-user and cooperative gestures. I will describe some gestures below.

7.5.1 **Throwing**

**Gesture:** Alike single-user gesture 8.1.2 (Dragging) it is possible to pass items over large distances. User A touches the photo with 3 fingers and makes a throwing motion while user B taps an empty location on the table with 3 fingers.

**Application:** This gesture is useful for passing photos over a digital tabletop, as found in [16]. Of course it can also be used to pass documents over the table during a meeting.

**Criteria:** This gesture might involve the whole screen, but if the two users cooperate well, this gesture works well because its purpose is clear and it feels intuitive.

7.5.2 **Pushing**

**Gesture:** Another gesture for transferring items over the display is this pushing gesture. User A places the edge of his hand on the table, aimed in a line toward the target image, and
can move his hand toward himself, dragging it along the table’s surface. This action causes candidate photos along this trajectory to blink, indicating that they are potential targets of this gesture. User B, who is seated near these target photos (and who may “own” them), can disambiguate A’s choice (and/or grant permission for A to take a photo that B owns) by tapping one of the blinking photos with a single finger. This image then slides across the table to user A.

**Application:** This gesture and its application are found in [16].

**Criteria:** This gesture is not very intuitive, and the two users have to cooperate well to succeed. It also involves a large portion of the screen and orientation problems might confuse the users as well.

### 7.5.3 Enlarging

**Gesture:** Four group members perform the enlarge gesture by simultaneously touching the corners of an item.

**Application:** Found in [16] to enlarge a single photo.

**Criteria:** Quite intuitive, but it might involve a big portion of the screen. Uses should communicate and cooperate well to let this work well.

### 7.5.4 Transfer ownership

**Gesture:** Two group members simultaneously touch the center of a photo to transfer its ownership.

**Application:** This gesture was found in [16] to transfer ownerships of photo’s, but of course this works for other items too.

**Criteria:** Very intuitive, small in size, and orientation is not an issue. But still this intuitive seems only useful if it is really important to transfer ownership in this way. Another way is to just tap on objects to make them yours. For most group meetings I think this works better and is easier to do.

### 7.5.5 Holding hands

**Gesture:** This is not really a gesture, but a precondition for an action to take place. All group members using the tabletop should hold hands and then one of the group members touches the display to take some action.

**Application:** This was found in [16]. After everybody holds hands one user opens the menu by tapping on the display and choosing Exit from the menu. This gesture makes sure everybody in the group agrees on the action taken place.

**Criteria:** The gesture is intuitive, but might not be accepted by users because of the need to hold hands with other users.

8. DISCUSSION

### 8.1 Group meeting application

In this section I will look at the gestures from a specific group meeting application. The meeting takes place with a group of four people around a tabletop device. They discuss a software prototype and have some digital documents and images to talk about. These documents and images can be passed around, dragged; images can be rotated and scaled. Table 1 shows whether a gesture matches the given criteria. Cond. stands for conditionally, which will be explained in section 8.1.2.

<table>
<thead>
<tr>
<th>Application</th>
<th>Intuitive</th>
<th>Orientation</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Pointing</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1.2 Dragging</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1.3 Lasso tool</td>
<td>Yes</td>
<td>Yes</td>
<td>Cond.</td>
</tr>
<tr>
<td>1.4 Marks</td>
<td>Cond.</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1.5 One F. rotation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2.1 Two F. rotation</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2.2 Two F. scaling</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3.1 Flat hand rotating</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3.2 Vertical hand</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3.3 Horizontal hand</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4.1 Two H. selection</td>
<td>Yes</td>
<td>Yes</td>
<td>Cond.</td>
</tr>
<tr>
<td>4.2 Two C.S. hands</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5.1 Throwing</td>
<td>Yes</td>
<td>Yes</td>
<td>Cond.</td>
</tr>
<tr>
<td>5.2 Pushing</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5.3 Enlarging</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5.4 Tr. ownership</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5.5 Holding hands</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

### 8.1.1 Good Gestures

Pointing (1.1), dragging (1.2), single finger rotation (1.5) two finger scaling (2.2), enlarging (5.3) and transferring ownership (5.4) are all surely useful gestures improving group work because they are intuitive and size and orientation is not an issue, so the table shows Yes for all criteria. For all gestures where it is said Orientation is not an issue I mean the gesture is easy to follow from every direction and does not confuse others. When I say Size is not an issue the gesture is small enough to perform on a small scale as not to hinder other users.

### 8.1.2 Discussable Gestures

For some gestures it depends on the circumstances (Cond. in table). The lasso tool (1.3) size might become an issue, but if users cooperate well and discuss what they are doing it will be fine. For the marks (1.4) intuitiveness can be an issue. The marks used should be easy to learn and intuitive, but that depends on the specific mark that is used. Its orientation and size should not be an issue. Two handed selection (4.1), and the throwing gesture (5.1) are intuitive gestures and just as with the lasso tool can work well if users cooperate and communicate what they are doing. The transferring of ownership (5.4) is a good gesture, but only necessary if people need to transfer ownership explicitly this way. Another way of transferring ownership is to just tap on object to let it be yours. This is much less work to do, so it hinders work less.
8.1.3 Bad Gestures

Gestures with No for at least one criterion are considered bad. Two finger rotation (2.1) is not intuitive enough and takes too much space. Flat hand rotating (3.1) is quite intuitive but blocks the view of others. The vertical (3.2) and horizontal hand (3.3) gestures are quite large in size. The two corner-shaped hands gesture (4.2) and the pushing gesture (5.2) are not intuitive enough. The holding of hands (5.5) is intuitive, but because of the need to hold hands it might not be accepted by many.

8.2 Input methods

From the research in [13] one might conclude the index finger is so intuitive it would be best to use only the index finger has an input method. But this limits functionality too much, and some actions would be very ambiguous. Other input methods are considered as well and shown useful. For example, the spread hand, shown to be the most useful after the index finger [13], or the use of two fingers at once can be very useful and these input methods ability to stay intuitive too. And, in relation to the size criteria, sometimes a small pencil will function better than a finger because it is smaller and therefore more precise.

8.3 Rotation

Rotations of objects occur often. In daily life, we often rotate an item, like a piece of paper or a photo, to show to another person. These gestures should be supported by tabletops too, especially because users around the table have a different interaction angle.

Some gestures applying rotation are difficult to learn and this might lead to confusing situations hindering the work that has to be done by the group. Users might argue about the right orientation or view and disagree. One solution is for users to have their own personal space, a small viewport, to work with on their own besides the central area of view. I think this can be very useful, but it is very application-dependant.

Kruger et al. [17] mentions rotation gestures should be lightweight and easy to understand. This matches the criteria for gestures, and therefore the one finger rotation (1.5) seems the best. Users should always be able to rotate items and to override automated rotation techniques by the system.

8.4 Cooperative gestures

Some of the cooperative gestures are very intuitive, such as the enlarge tool, but others are not that easy to learn.

Overall, cooperative gestures vary in size and some of the gestures need a lot of space to function. Users should communicate about the actions that should be taken, or else the situation gets confused and the work gets hindered.

Research done by Morris et al. [16] shows that people do not like physical contact when using tabletops. The holding hands (5.5) gesture is a good example of a gesture people might not like. I think people should just communicate and together decide what has to be done next, instead of explicitly holding hands to say you agree with each other.

The pushing gesture (5.2) is a good example of a difficult gesture. It is not intuitive. Morris et al. [16] noticed this gesture received the lowest scores after evaluation.

9. CONCLUSIONS

The main conclusion of my research is quite simple: *Keep gestures simple!* Multi-touch, multi-user tabletops are able to increase collaborative group work and enhance face-to-face-communication, as concluded by others and gestures pay a big role in the interaction. Gestures should not hinder group work; therefore, the following criteria are important:

- **Intuitiveness**: Gestures should be intuitive and easy to learn. A gesture is intuitive when users recognize the behavior from daily life around real tables or from experience with other interaction methods in the past.
- **Orientation**: Gestures should be the same in every direction, so users on the other side of the table recognize the gestures easily. Items involved in the interaction should easily rotate when users want to.
- **Size**: Gestures should not be too large in size and should not block the view of other users.

To answer the research question: Gestures are improving group work around tabletops if they match the given criteria. Section 8.1 and Table 1 show which gestures are useful while working with a group meeting application.

People should discuss the contents of their work, and not the gestures they are using. If gestures are easy to learn and intuitive, they are used fluently while working and people are still able to discuss the contents of their work.

Hilligis et al. [2] conclude collaborative decision-making can be promoted by providing group members with equal access and direct interaction with digital information. The article also notes that interaction might be extended with the use of voice and speech recognition, which I agree with.

The list of gestures I gave is a current state-of-the-art of what gestures are being used in tabletop interaction. I hope that besides the conclusions I presented, the icons I created might be useful too. For example, they could be used for instruction manuals for tabletop software. I based the icons on icons created by Wu et al. [14].

Concluding, multi-touch is a great technology and we will see it everywhere in the near future. For example, Windows 7, the follow-up of Microsoft’s Windows Vista, will be the first operating system to fully support multi-touch input. Multi-touch, especially with the combination of multi-user support, can be of great assistance while performing collaborative group work and can really enhance the performance, if the interaction stays intuitive and gestures are not too complex to handle.

10. FURTHER WORK

My conclusion that gestures should not be too large, intuitive and not too complex is true for collaborative group work, but might not be true in other areas such as a multiplayer game.

With such applications it might really be necessary to use complex and large gestures to win a game. I leave that discussion open for further research, as I focused my study only on the effectiveness of multi-user, multi-table tabletop interaction when performing collaborative group work.

Further work in the field of tabletop interaction should always take into account the gestures are intuitive and easy to learn. If a new gesture is invented, a use case, a test case or some other research should examine the usability of the gesture.

As I mentioned, the icons I created might be useful for instruction manuals. I would like to add the remark that these
manuals should not always be necessary as gestures should be easy to learn, as concluded earlier. Still, some applications might benefit from clear manuals. Think of user groups that have difficulties with a specific technique, like older people or people that did not work with well known operating systems like Microsoft Windows.

Clear to me is that further work in the field of multi-touch, multi-user interaction techniques looks promising and if we can keep the gestures intuitive and easy group work can really benefit from theses tabletop devices.

REFERENCES


