Collaborative problem solving on mobile hand-held devices and stationary multi-touch interfaces

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ABSTRACT

This paper focuses on the coupling of mobile hand-helds with a stationary multi-touch table top device for collaborative purposes. For different fields of application, such as the health care domain, the coupling of these two technologies is promising. For the example of sudoku puzzles we evaluated the collaboration between multi-touch table top devices and mobile hand-helds. During the small-scale evaluation we focused on the differences between face-to-face collaboration and remote collaboration when solving problems collaboratively on table top devices and hand-helds.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces; H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces

Keywords

Multi-touch user interfaces, Mobile user interfaces, Multi-touch devices, Group interfaces, Collaboration

1. INTRODUCTION

In various computer applications the user has or wants to collaborate with other users. The role of the user interface is to optimally assist the collaboration of users. Whereas broader research has been performed on collaboration via desktop computers, there exists less experience on the collaboration using mobile or table top devices. For practical applications the combination of these two technologies is of special interest.

The challenge is, that the way of interacting with the mobile devices typically differs significantly from the interaction with table top devices. Whereas mobile devices are typically only used by a single user at a time, simultaneous multi-user input is possible on table top devices, especially when multi-touch devices are used. Moreover, the possibilities to present all relevant information to the user are substantially more limited on mobile devices than on table top interfaces.

1.1 Mass casualty incidents

In different fields of application the coupling of a table top device with mobile hand-helds makes sense. We plan to improve the collaboration of paramedics or doctors with the operation control center in mass casualty incidents by coupling mobile hand-helds with a multi-touch table top. Whereas paramedics and doctors require high mobility in order to be able to move around in the field, the operation controllers require an overview of the overall situation. Therefore equipping the paramedics with mobile devices and equipping the operation control center with a table top device would make sense. The operation control center as well as the paramedics retrieve from and store to the system all patient related information [10].

The way of presenting the information on mobile devices on the one hand and on the table top device on the other hand differ slightly. Whereas on the table top device information on the overall situation is presented, on the mobile devices the information on specific patients is of primary importance.

1.2 Modalities of collaboration

When coupling mobile devices with a multi-touch table top two entirely different ways of collaboration are possible. Either the table top device facilitates direct collaboration or the mobile devices facilitate remote collaboration. The collaboration on the table top device includes the possibility to directly keep track of all users' interactions, to point at problematic areas and to discuss face-to-face. When using mobile hand-helds, the users not necessarily have to be in the same room, they can freely move around during the collaboration. By combining the table top device with mobile hand-helds we expect to take the advantages of both technologies.

1.3 Sudoku

The concrete problem which we chose for the first evaluation of the collaboration between multi-touch table top devices and mobile hand-helds was the sudoku puzzle. We chose the

Table 1: Sudoku solution (Start values are written in bold).

7	**9**	**4**	5	8	2	**1**	**3**	6
2	6	8	9	3	1	7	4	5
3	1	5	4	**7**	**6**	9	8	**2**
6	**8**	9	7	**1**	5	3	2	4
4	**3**	**2**	8	6	9	5	7	1
1	5	7	**2**	4	3	8	**6**	9
8	2	1	6	**5**	7	**4**	9	3
9	4	3	1	2	**8**	6	5	**7**
5	7	**6**	**3**	9	**4**	2	1	**8**

sudoku puzzle because previous research has been performed on the exploration of relationships at the example of sudoku games by Klinker et al. [7]. First of all we want to focus on the question of collaboration between mobile and table-top devices, this subproblem can be represented at the example of sudoku.

We implemented this puzzle on the table top device as well as on the mobile devices. This puzzle consists of a 9*9 grid, the grid consists of nine 3*3 sub-grids. The puzzle has to be filled with numbers from 1 to 9 in a way, that each row, column and sub-grid contains every number exactly once, as shown in Table 1. On the basis of given start values the sudoku puzzle typically is uniquely solvable.

At first glance sudoku seems to be an absolute single player game. This is not true, in fact there are extended possibilities for collaborative solving. Especially because of the indirect dependence of the numbers from 1 to 9, the game can be solved collaboratively by assigning one or more numbers to each player. This simple subdivision of the entire problem facilitates the collaborative solving by up to nine players. Note that a similar subdivision exists in mass casualty incidents when assigning one or more patients to each paramedic or doctor.

2. RELATED WORK

Previous research on coupling mobile hand-held devices with public displays has been performed. The approach of Greenberg et al. [3, 4] bases on hand-held devices with personal information and large displays with public information. During a real time meeting the participants can share personal information and modify all public information. Carter et al. [1] proposed a combination of public displays with hand-held devices for public annotation of multimedia content. They used hand-held devices to augment, comment and annotate public content which is displayed on public displays. In the health-care domain public and private displays were used by Favela et al. [2]. They supported the decision making of doctors and nurses with mobile computing technologies. Furthermore they proposed a concept to integrate public displays in this ubiquitous application. Semi-public displays for collaboration within smaller groups have been developed by Huang et al. [6]. Their concept focuses on sharing information on activities within certain user groups. Information shared by group members is not fully public, it can be only viewed and modified by group members.

3. SYSTEM SETUP

For playing the sudoku puzzle collaboratively on the mobile hand-helds and the stationary table top device we designed a simple system architecture. The state of the sudoku game can be described by a string of 81 characters (assuming that a standard sudoku puzzle with a 9*9 grid is played). Starting in the upper left corner of the grid, all fields of the grid are listed row-by-row. In summary each field can take on one of 19 different states, besides the *empty* state (represented by *0*) it can contain a *user state* from 1 to 9 (represented by *1-9*) or a *start state* from 1 to 9 (represented by *A-I*). The current system architecture bases on a client-server model. The table top serves as the server to which the mobile hand-helds are connected via a wireless network. The current communication protocol is restricted to the commands which are compulsorily necessary for the collaborative solving of a sudoku puzzle:

- **State?**
  Client request for sending the current state of the sudoku puzzle
- **State! <valueString>**
  Client request for setting the current state of the sudoku puzzle to the state which is described by the *valueString*
- **State <valueString>**
  Server response on both state requests with the state contained in the *valueString*
- **Action? <x> <y> <value>**
  Client request for setting the field in column x and row y to *value*
- **Action <x> <y> <value>**
  Server response on an action request containing the *value* for the field in column x and row y

The requests for changing the server state typically succeed, provided that the *valueString* is syntactically and semantically correct. The string has to contain 81 characters from 0-9 or A-I to be syntactically correct. In order to suceeed the test on semantical correctness, the *start states* in the sudoku puzzle must be arranged in a way that the sudoku is solvable. For instance, each of the characters A-I may occur only once in each row, column and sub-grid. The fields filled with *user states*, however, are not tested during the semantical test because the sudoku remains solvable even if the user states are semantically inconsistent (assumed that the user interface contains the functionality to go back). On the one hand clients can join a running game by sending the *State?* request and on the other hand the clients can share their game to other clients by sending the *State!* request.

The requests for performing actions are slightly more complicated. An action which a client wants to perform can fail for two reasons: The client tries to overwrite a field filled with a *start state* with a *user state* or a other client tries to change the field at the same time. When one of these conflicts occurs, the server sends the current field state (which differs from the state requested by the client) in his *action* response to inform the client that his action failed. This

Figure 1: Sudoku puzzle on the multi-touch table top

Figure 2: Sudoku puzzle on mobile devices

concept is generally completely resistant against state inconsistencies because of the fact that a central server decides whose action succeeds and whose fails.

4. USER INTERFACE

As stated above, two different user interfaces are necessary for the two interaction modalities. The table top system has to support multiple concurrent users, while the mobile UI should be easily usable with a stylus.

4.1 Table top device

Multi-touch technologies for public displays have first been developed by Lee et al. in 1985 [9]. The multi-touch table top which we used for our implementation is based on the technology proposed by Han [5]. The table top user interface is presented in Figure 1. It was inspired by the JigSawDoku browser game [8]. On the left and right side of the grid, users are presented a selection of colored number tiles. Fixed numbers are shown with a white background. Users can drag and drop the colored tiles into the free fields of the sudoku grid by simply touching and moving them with their fingers. As the table top system provides multi-touch input, several users can concurrently move and place tiles. As the users can view the table from any side, the tiles show each number in four different orientations. To ease correct placement, the tiles snap into the free fields below a certain distance. During the game, users can quickly determine the approximate number of fields left for a certain number by looking at the tile colors. When the grid has been filled correctly, a message is displayed that the game has finished. The time which users took to complete the puzzle is displayed on top of the screen as well as logged to a file for later evaluation.

All tiles which are placed in the table top interface are wirelessly transmitted to the hand-helds and also displayed there. Vice versa, when a number is set on the hand-held, one of the free tiles on the table top is moved to the correct cell with a short animation.

4.2 Mobile hand-helds

The user interface for the mobile hand-held devices is shown in Figure 2. Due to the fact that screen space is highly limited when developing for mobile hand-helds the visualization differs from the one for the table top device. For the benefit of overview we had to do without displaying all unset tiles separately. Otherwise the space would have been too limited to show the complete sudoku grid at once. Thus the user interface then would have to contain intuitive metaphors to scroll, pan and zoom. Therefore we alternatively sorted all unset tiles on 9 different stacks and indicated the height of these stacks numerically.

The metaphor for moving tiles slightly differs from the one for the table top. During a review with experts we found out that the movement of tiles by the "'stick-to-finger"' metaphor is very inaccurate for hand-held devices. However, separat-

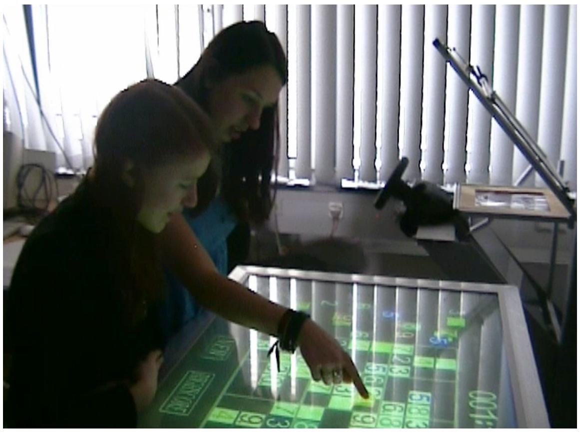

Figure 3: Evaluation of the sudoku puzzle in a small-scale user-study

ing the tile movement into the two steps *tile selection* and *tile placement* worked quite well, when performing both of these sub-actions with a separate click. First the user clicks on the tile which he wants to place and afterward he clicks on the field which he wants to fill with that tile. Furthermore when the user wants to place several tiles from the same stack, the first click is not required because the tile stacks remain selected. Additionally a tenth stack was included, the "'empty stack"' which can be used to clear *user state* fields. The metaphor for clearing fields works in analogy to the one for filling fields: first the empty stack and then the field which has to be cleared is selected. The height of the "'empty stack"' indicates the number of tiles which have still to be set in the current game.

5. EVALUATION

In addition to the expert review we performed a small-scale evaluation to determine the advantages of coupling mobile hand-helds with table top devices. In the user study shown in Figure 3 we focused on the impact of physical presence on the effectiveness of collaboration. The better the two user-interfaces support collaborative problem solving the less face-to-face discussions are essential for successful problem solving. Therefore we compared in the evaluation the effectiveness of face-to-face and remote collaboration in a quantitative manner. The subjective impression of the participants was identified by a questionnaire.

In total 16 people participated in our small-scale user study. Their objective was to solve five different sudoku puzzles collaboratively in teams of four. We evaluated three different alternatives of collaboration:

- **Table top.** All four people are collaborating at the table top
- **Face-to-face.** Two people are collaborating at the table top, two people are equipped with hand-helds. All participants are in the same room.
- **Remote.** Similar to *face-to-face*, but all participants are in different rooms (except the two at the table top).

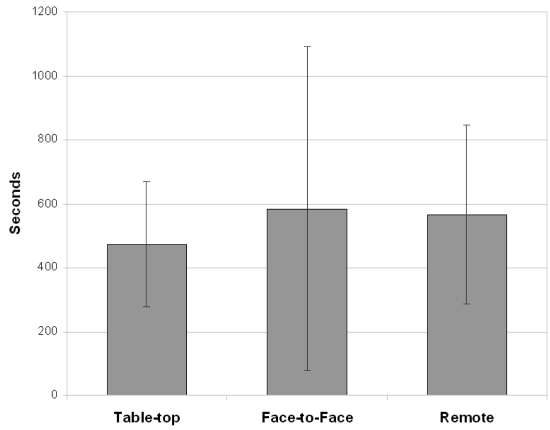

Figure 4: Quantitative evaluation results

Due to the fact that we wanted every participant to evaluate the *face-to-face* collaboration and the *remote* collaboration on the hand-held as well as on the table top we needed two cycles for these two alternatives. In summary five alternatives had to be evaluated by our four teams. We permuted the order of the alternatives to avoid training effects and to compensate potential differences in the difficulty of the five sudoku puzzles.

The quantitative results of the user-study are shown in Figure 4. When using the table top device the users solved the sudoku puzzle within 473 seconds in average (SD: 194 s), whereas the face-to-face collaboration needed 585 seconds (SD: 506 s) and the remote collaboration needed 566 seconds in average (SD: 280 s). As a consequence the null hypothesis could not be rejected in this small scale user-study. Face-to-face collaboration, however, seems not to be faster than remote collaboration when using hand held devices. This is a quite remarkable result when it can be approved in a larger user-study. On basis of this first small-scale evaluation we can assume that collaboration works best when the users are not only in the same room but also working on the same device.

In addition to the quantitative evaluation the subjective impression of the 16 participants was documented by a simple questionnaire which consisted of six questions:

- Which interface you did enjoy more? (1..table top – 5..hand-held): **2,4 (SD: 1,4)**
- Which interface was more efficient? (1..table top – 5..hand-held): **2,6 (SD: 1,3)**
- Have you been disturbed by the actions of other players when you played on the hand-held? (1..very often – 5..never): **3,1 (SD: 1,2)**
- Have you been disturbed by the actions of other players when you played at the table top? (1..very often – 5..never): **1,9 (SD: 0,7)**
- How present were the other players when you played

on the hand-held? (1..very present – 5..not present): **2,5 (SD: 1,0)**

- How present were the other players when you played at the table top? (1..very present – 5..not present): **2,1 (SD: 0,9)**

Regarding the interface the participants could not clearly decide between the table top and the hand-held device. The users on the table top were often disturbed by the hand-held users whereas they were not that much disturbing for the hand-held players. On the other hand the high disturbance leads to a high presence of the hand-held players.

6. CONCLUSION AND FUTURE WORK

We presented an approach to couple mobile hand-helds with a stationary multi-touch table top device. The evaluation showed that mobile hand-helds enable the users to remotely collaborate with users playing on the table top. Whereas a table top offers possibilities for direct collaboration, the physical presence of all participants can not be guaranteed in all applications. Therefore the extension of existing table top applications with mobile user-interfaces leads to an enrichment for the hole application. The future work will be to find out how the different modalities of collaboration work in detail. For instance it is interesting, whether the contribution of every single player depends on the used input device.

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