Analysing the Effect of Tangibile User Interfaces on Spatial Memory

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ABSTRACT

Tangible User Interfaces (TUIs) allow for effective and easy interaction with digital information by encapsulating them into a physical form. Especially in combination with interactive surfaces, TUIs have been studied in a variety of forms and application cases. By taking advantage of the human abilities to grasp and manipulate they ease collaboration and learning. In this paper we study the effects of TUIs on spatial memory. In our study we compare participants' performance of recalling positions of buildings that they priorly placed on an interactive tabletop either using a TUI or a touch-based GUI. While 83,3% of the participants reported in their self assessment that they performed better in recalling the positions when using the GUI our results show that participants were on an average 24.5% more accurate when using the TUI.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**;

KEYWORDS

Spatial Memory, Tangible User Interface, Spatial Information

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Figure 1: A Tangible User Interface utilizing 3D-printed tangibles arranged on a digital map.

1 INTRODUCTION

Since the existence of mankind, spatial memory has played an important role in the process of humans navigating and orientating in spatial environments. As shown by a wide range of research across various domains, humans have developed remarkable skills for sensing and manipulating their physical environment [5]. Starting from childhood, the development of spatial abilities is part of the daily routines of most humans. This applies to large-scale environments, e.g., for safely returning back home, as well as to smaller environmental scales, such as grasping a pen. Encapsulating digital information into a physical shape that allows the human brain to easily store and retrieve them is one of the key ideas behind Tangible User Interfaces (TUIs) [3]. This is very similar to the haptic feedback of mnemonic devices [1], which have been proven to be extremely helpful in generating working memory. TUIs built upon the human ability to grasp and manipulate physical objects and can have beneficial effects on the spatial memory, especially when being used for interacting with spatial data.

While it is generally accepted that TUI's help increasing spatial memory, this is mostly anecdotal, and only very few papers have empirical evidence on the positive effects. Kim and Maher showed that using TUIs in a creative design process has a positive effect on the users' spatial cognition [4]. When comparing TUIs and GUIs for learning and recalling relationships between objects, TUIs have been show to have a positive effect on recalling spatial relationships [6]. In this paper we want to contribute to this line of research and give further evidence on the positive effects of TUIs on spatial memory. We conducted a study comparing the participants' performance of recalling locations of buildings on a digital map as a spatial user interface. Prior to recalling the locations, the participants were asked to place the buildings onto the map either using a TUI or a graphical user interface (GUI) utilizing direct touch input. We found that although 83.3% of the participants reported that they thought to have performed better using the GUI, they recalled the locations on average 24.5% more accurate using a Tangible User Interface.

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2 RELATED WORK

When memorizing spatial information, humans encode, store, and retrieve their spatial knowledge by making use of their internal mental spatial representations which are typically not geometrically accurate [5]. However, the knowledge is acquired in multiple stages: first, one learns individual object-place knowledge, later, knowledge about routes and lastly, environmental shape knowledge is acquired with increasing experience of the physical world or other external spatial representations. In the context of this work, the participants have to acquire object-place knowledge in a small-scale environment where head and eye movements are sufficient to explore and interact with the 3D-printed buildings on the tabletop.

A direct benefit, resulting from the use of TUIs, is that humans can re-apply their haptic skills as well as problem solving strategies to interact with a computer. It has been found that people tend to use spatial arrangement strategies that were based on an external reference frame when interacting with TUIs [6]. In that task, they spatially arranged visually identical wooden blocks and icons in a GUI to model contextual relationships of news articles. Also, in the position recalling task, the participants performed significantly better when using TUIs. This already hints that TUIs support the generation of spatial memory, but as it was not the main focus of the study, it is no clear evidence. Quarles et al. [9] compared a real device, a virtual representation on a desktop computer and a magic lens interfaces presenting an AR overlay in terms of the participants ability to recall certain positions on an anesthesia machine. They found that participants performed better in recalling locations when using the magic lens in comparison to the GUI setting. But their magic lens approach is a rather wide interpretation of a TUI.

The so far most solid evidence of the benefits of TUI's on spatial memory has been provided by Kim and Maher [4]. They compared a 2D GUI against a 3D tangible version of a design interface and proved that the TUI version had a positive effect on designers' spatial cognition. While it helped understanding the designs spatial orientation and arrangement, they did not prove that it actually helped generating spatial memory of the design. Additionally they compared two indirect interaction techniques, as their 3D tangibles manipulated objects on an additional screen. In this paper we extend on their work and demonstrate the ability of TUI's to help in the creation of spatial memory.

Several application cases for the exploitation of spatial memory have been studied. Ishii and Ullmer proposed the Tangible Geospace, which used physical icons to model outstanding buildings of the MIT campus as tangible interfaces to control the digital map. With their natural affordances and physical constraints, the tangibles provided two-handed and multi-user interaction [3]. Urp is another system that employs TUIs in the spatial domain, in this case for urban planning [10] in which the individual building models were distinct and the effects of changing the spatial configuration could be simulated interactively. Tangibles have been shown to be helpful when trying to learn spatial properties of three-dimensional objects [2]. Moreover, TUIs have also been used to create, form, and analyze spatial entities. For landscape modeling, clay was used as the tangible part in combination with a projector and laser scanner [8].

3 USER STUDY

In order to analyze the effect of a TUI on spatial memory we set up a study that compares user interaction of a TUI to touch interaction on a tabletop in a spatial mapping task. Participants had to arrange a set of buildings on a map using one of the two techniques and later on were asked to remember the positions in a desktop setting using a mouse. We chose the map interaction task as it represents a good task for actual spatial memory that could be transferred to other settings. Additionally geographic and map applications have already been proven to be viable application cases for TUIs [7, 8, 10]. Our study setup is based on studies in spatial cognition that investigate the development of spatial memory. These first allow the participants to explore the given environment on their own and for the recall part of the environment using a different setting [?].

3.1 Apparatus

The two conditions in our study are: *Touch* and *TUI*. In the *Touch* condition the users used a standard touch-based drag and drop metaphor to relocate the buildings, while in the *TUI* the participants had to pick up a 3D printed object of one of the buildings, and place it on one of the markers on the map. For the study we used a Samsung SUR40 tabletop (21.7pixel per cm resolution) and the built-in Microsoft PixelSense Fiducial Marker tracking for the tangibles.

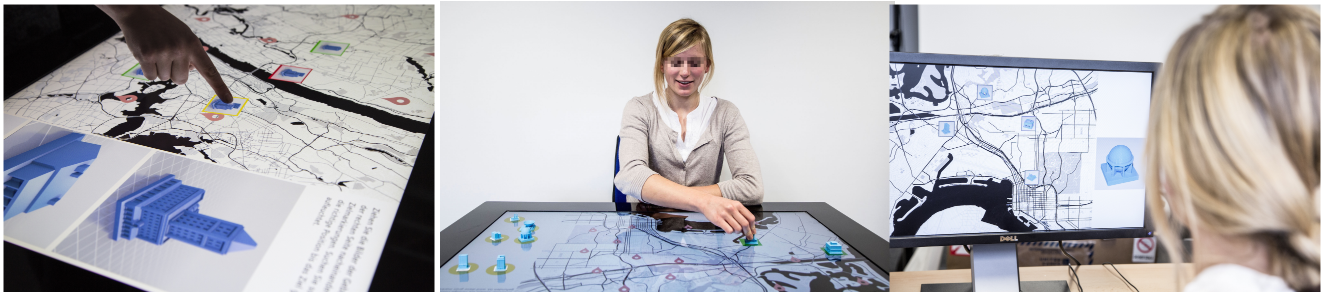
3.2 Task

The task employed in this study was a map interaction task in which the participants had to first find positions of buildings on a map through arranging them in a trial and error manner and then remember these positions. The study was split into two parts, the placement and the recall part. First participants always had to complete the placement part in which they were asked to arrange 8 buildings on the map. The map contained 16 markers and participants were not aware of the relationships of these markers and the buildings. The buildings - either in a 3D printed form or as an image representation - were placed on the right side of the tabletop and participants had to arrange them on one of 16 markers located on the map. If the building was placed on a wrong marker, a red square would be shown around the building and if they were placed on the right marker a green square would highlight the position. Participants were free in either locating one building after another or several at the same time (see Figure 2a and b). The task was finished once all buildings were located on the right marker.

After the placement part the participants had to recall the positions of the buildings and place images of the buildings on the map (see Figure 2c). For this they physically switched from the tabletop to a desktop computer where the images were placed using a mouse. This switch was done to show the applicability of the gained spatial memory across different settings. The map did not contain any of the markers shown beforehand. This was inspired by the procedure of studies in spatial cognition [5].

As we wanted to use no well-known buildings we decided to use a set of Sim City 2000 buildings from Thingiverse[1]. In the placement part we used the images from Thingiverse for the touch interaction and the 3D printed buildings (printed with an Ultimaker 2) for the TUI interaction. In the recall part we would use the Thingiverse

[1] http://www.thingiverse.com/thing:12673



(a) GUI positioning **(b) TUI positioning** **(c) Recalling task**

Figure 2: The building icons were moved using standard touch dragging in (a). In (b), the tangibles could be freely moved on the table; building that still had to be placed on the map were located on the lefthand side of the tabletop. The recalling (c) task was performed on a desktop computer using a mouse.

images if the participant priorly placed the buildings using touch and an actual picture of the 3D printed building if he used a TUI. For the maps we used a variant of the stamen toner map[2] without any street or place names. This was done so that participants had no aids through e.g., street names. We used two different maps (San Diego and New York City) and placed 16 markers on these maps at random points. Each marker was assigned one of the buildings. After that we split the buildings into two sets, where each building would only occur once in each set. Participants would use one of the sets with one of the maps for the first condition and the other set of buildings and the other map for the second condition.

3.3 Procedure

20 volunteers (8 female) aged between 21 and 38 (μ = 29.2) were recruited from our research institution. All were right- handed, familiar with touch-screen technologies, and 12 had used a tabletop interface before. We used a within-subjects experimental design where each participant had to use both conditions with different sets. The conditions, building sets and maps were counterbalanced across participants. The task was explained individually to each participant who could try out both condition with a demo set prior to the whole study.

The independent variables were: The different interaction techniques: TUI and Touch. The two different sets: Set 1 or Set 2. For each set 8 different buildings were used. Overall we recorded 320 data points (20 participants x 2 conditions x 8 buildings).

3.4 Measures

The experimental software recorded trial completion time (CT) during the placement part as well as in the recall part of the study. Furthermore for both parts we recorded the position of a building each time it was placed on the map either using touch or TUI respectively using the mouse in the recall part. After each placement task we asked the participants to complete a questionnaire consisting of a NASA TLX and an ISO 9241-9 questionnaire (both using a 5-point Likert scale). This questionnaire was introduced as an additional cognitive task such that the participants could not solely focus on remembering the positions. After the second recall task the participants had to self asses for which condition they performed better in the recall task.

3.5 Results

We calculated the euclidean distance from the final position of each building that the participants placed them in the recall part to its actual correct position in pixel. All results even extreme outliers (e.g. if a participant had forgotten the original placement and was rather guessing) were included for our analysis. On average participants placed the buildings in the recall part 201pixel which is equal to 9,2cm on the Samsung SUR40 (SD 27pixel) away from their actual position when using the TUI condition and 266pixel which is equal to 12,2cm on the Samsung SUR40 (SD 35pixel) away when using the touch condition. A repeated measures ANOVA and Bonferroni-Corrected post-hoc tests showed a statistically significant difference $p<0.04$, $F = 5.7$ between the two conditions. This means that participants performed significantly better (24.5%) when using the TUI condition. A repeated measures ANOVA found no significant difference between the two sets or the two maps.

While we found no difference in terms of task completion time, neither for the placement nor for the recall part of the study, we found a significant difference in number of changed locations in the recall part of the study. Participants on average relocated buildings 2.3 times (SD 1.1) for the TUI condition after they first placed them with the mouse. In the GUI condition this only happened on average 0.8 times (SD 0.5). A repeated measures ANOVA found a significant difference $p<0.03$, $F = 4.2$ between the two conditions.

The idea behind the NASA TLX and ISO 9241-9 questionnaires was only to create some distraction between the placement and recall task, nevertheless they hold some insights into the two interaction techniques. Only two questions had a significant difference (repeated measures ANOVA and Bonferroni-Corrected post-hoc tests). The first was the physical demand of the NASA TLX, where the TUI condition was rated at 2.08 and the GUI condition had a higher score with 3.1. The second question was the Finger fatigue question of the ISO 9241-9 where the TUI condition performed significantly better compared to the GUI condition (1.92 vs 3.2). Both results are not surprising given prior work and the general

[2]http://maps.stamen.com/

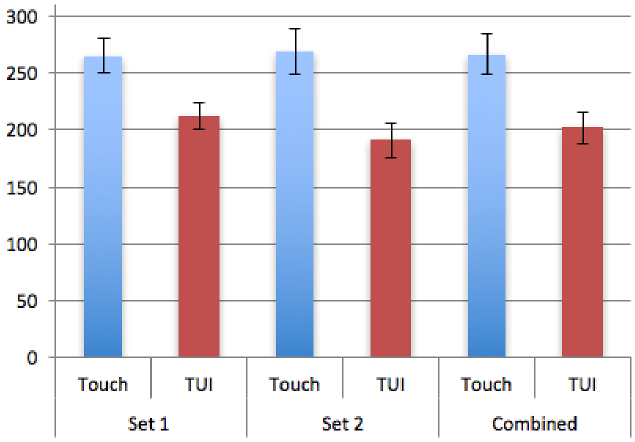


Figure 3: Distance in px from the actual position of the buildings using either touch interaction or the TUI.

setting, as dragging on the Samsung SUR40 is not very comfortable over long distances.

For the self assessment of their performance 15 of the 20 participants rated that they performed better in recalling the positions when using touch. 13 participants stated that they found it easier because the images used were in both parts the same.

4 DISCUSSION

In the self-assessment, the majority of the participants might have reported their individual performance to be better in the Touch condition compared to the TUI condition, because the recognition value of the images was higher. We used the same images on the tabletop as in the recall task on the desktop computer for the GUI condition. As we used pictures of the 3D printed buildings in the TUI condition, these had the potential to create a perspective and lightning mismatch when transferring the memorized locations in the recall part. Thus, the identification of the object in the recall task felt subjectively easier to the participants while at the same time finding the correct position was more difficult. However, the objective performance in the recall task still was significantly lower in the Touch condition, which must therefore be explained with other effects. Additionally, the fact that participants relocated the images in the recall part of the TUI condition more frequently suggest that they first placed the buildings and then differentiated them on their unique characteristics again through relocation.

However, even though the study was explicitly designed such that the recall task for the TUI condition was more difficult as for the GUI condition, the participants objectively performed better in the TUI condition. This underpins the idea that TUIs have a positive influence on generating spatial memory. Our findings provide further empirical evidence on this matter that extend the work of Kim and Maher [4].

The interaction in both tasks was implemented completely equal, including the possibility of using two hands and multiple buildings at once. The significant difference in the objective performance can be explained by the perceptual differences during the task executions [6]. Besides that, we suspect that the interaction with 3D-printed buildings encourages the use of an external spatial reference system. The participants interact with them as with any other physical object in space and might be able to estimate distances more accurately relying upon stereoscopic viewing.

5 CONCLUSION & FUTURE WORK

In this paper we continue the work of Kim and Maher [4] and presented a further investigation on the effects of TUIs on spatial memory. In our study we compared participants' performance of recalling positions of buildings that they priorly placed on an interactive tabletop either using a TUI or a touch-based GUI. While 83,3% of the participants reported in their self assessment that they performed better in recalling the positions when using the GUI our results show that participants were on an average 24.5% more accurate when using the TUI.

For future work we want to verify the experimental results by accounting for the differences of the recognition value of the images by, e. g. handing the participant the current building model that has to be positioned during the recall task. We would expect that to strengthen the effect.

Another addition could be to assess the different memorization strategies that participants would typically apply. We would like to have evidence if there are some strategies that are used in the GUI or TUI condition only and others, which are applied in both settings. For example, the significant performance advantage could be due to an increase in the use of visual features of the map, the use of external reference frames, rather than solely relative positioning.

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