Interaction Design and Information Visualization for Wall-Size Displays with User Tracking

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1 Introduction

The use of wall-size displays are becoming increasingly popular in the corporate world and as a research subject due to declining prices and high availability. However, many questions about how to effectively interact with and utilize wall-size displays still exist.

Wall-size displays as a research subject began in the early nineties with the introduction of LIVEBOARD in 1992 and CAVE in 1993 [18, 12] which were mainly technical descriptions. Since, much work on wall-size displays have continued to primarily focus on the technical implementation - such as how to construct and run tiled LCD arrays, how to align projected images from video projectors, etc. [27, 31].

Nevertheless, much work have also been done with focus on the difference between regular displays and wall-size displays in terms of how we interact with them and what we gain from them. The need for this were realized earlier on by Swaminathan and Sato who in their 1997 paper wrote:

> [...] when we started, we thought of a large display as basically the same as a regular display, just larger! We no longer do so. We think that when a display exceeds a certain size, it becomes qualitatively different: different design issues come into play and interaction deign becomes full-blown environment design. [35]

Recently Tao Ni and colleagues identified *"effective interaction techniques"* as one of the top ten research challenges associated with large high-resolution displays [27].

Based on this insight, much of the research have also aimed at developing effective techniques for targeting and selecting objects using various tools and gestures. Results show that well designed interaction techniques can increase efficiency substantially [2, 1, 5, 21, 10, 7].

Recently the research have began to better understand the factors that make wall-size displays work well. These are especially factors that stem from peoples embodied resources such as opportunity of physical navigation and increased peripheral vision. North and Ball showed in [3] that increased efficiency especially is a result of physical navigation, but that a combination of the two factors are beneficial.

However, very little research exist in terms of information visualization for wall-size displays. As one of the only studies exploring the subject is [28] which evaluates the perceptual scalability of visualizations. The authors also identifies important questions to be asked when designing information visualization for wall-size displays. These are questions such as: *When the screen isn't the limiting factor, just how much data can a person effectively perceive? As more data is shown whith increasingly larger displays, do we hit a breaking point, the limits of visualization?* and *How will visualizations for large displays need to fundamentally differ from visualizations on desktop displays? I.e. how are basic visualization design principles different on large displays?* Their results showed that some visualizations scale well - i.e. scaling did not result in an increase in task completion time or a significant decrease in accuracy.

Although research points to physical navigation as being a main source of increased efficiency no one have tried to harness knowledge about users position and movement in a beneficial way.

In this thesis I propose two approaches to interaction design for wall-size displays that employs user tracking. The idea is that by utilizing users position and movement as primary mean of navigation users exploit use of their embodied resources for more natural and efficient interaction.

Two approaches are proposed. The first, denoted position interaction , utilizes users' position relative to the display for determining what area of the virtual space is visible. Sideways movement maps to sideways panning and forward movement maps to the level of magnification in virtual space. To allow the user to access a larger virtual space than accessible via direct mapping from physical space, hot zones for automatic scrolling in the left and right edge have been implemented. The second approach, denoted motion interaction , uses state dependent sideways tracking; i.e. tracking are only enabled for sideways movement when the user presses a button. This allows the user to be in greater control of horizontal panning as well as access non-direct mappable areas of the virtual space by employing a move-reset-move technique known from computer mice.

Because of perspective distortion experienced by the user when being close to the display a scale correction visualization technique were employed. This meant that virtual objects far from the user were increased in size to maintain constant visual acuity.

These approaches of interaction and information visualization with user tracking makes for an theoretically interesting study that can uncover essential issues with this kind of systems.

This report accounts for the development of the two user tracking approaches to interaction design and tailored information visualization (from now on denoted user tracking approaches) by discussion of design alternatives and design choices. Furthermore an empirical study has been carried out to evaluate the relative performance of the two user tracking approaches compared to each other as well as a control case using a regular gyroscopic mouse.

Results of the empirical study are somewhat inconclusive. No significant difference in average task completion time, accuracy or user satisfaction were measured. Analysis suggest that technical issues with the implementation hindered the two user tracking approaches from exploiting their full potential. Furthermore, the short duration of experiments and introduction for each interaction type might have held participants from reaching a adequate level of experience to gain full potential from their embodied resources. I suggest that future research aim to ensure a proper technical implementation as well as study the effects of long term use. Furthermore there is interesting potential in exploring interaction design and information visualization with user tracking in the context of multiple simultaneous users.

A video presentation of the implemented system in action are available from `http://www.thomassidor.com/UserTracking`.

1.1 Reading guide

This report is split up in four main parts. Part I presents related work in the area of wall-size displays including technical considerations and research in interaction design and information visualization for wall-size displays. In part II I present a discussion of possible designs of interaction design and information visualization for wall-size displays in the context of user tracking. Part III describes the design of and results from an empirical study used for testing the two proposed designs relative to a regular approach using a gyroscopic mouse. Finally, part IV discusses and concludes on the results from the empirical study as well as observations about interaction design and information visualization in general. Furthermore this part lays out suggestions for improvements to the tested designs as well as suggestions for future work.

2 Problem statement

In this section I describe the motivation for the subject of the thesis and the ideas to why interaction design and information visualization with user tracking could prove beneficial for users. The original problem formulation for this thesis were defined as two essential questions:

- *What interaction patterns using user location tracking are feasible for wall-size displays and how can information visualization techniques be tailored to this context?*
- *Compared to prevalent interaction patterns and non-tailored visualization techniques, how does a suggested approach, based on user location tracking, perform using common measurements of usability?*

Large wall-size displays are becoming more popular, and so is it as a research subject. However only little research have been aimed at understanding user's physical presence in front of these displays. In [29] North and Ball evaluated the effects of physical navigation and peripheral vision on large scale visualizations. Their aim was to uncover how much these factors contribute to changes in efficiency. Drawing inspiration from this study ideas about how the opportunity of physical navigation could be exploited more effectively began to appear. What was apparent from the previous work was that physical navigation has been studied as something you do to get more information in an easy manner - i.e. you move from one part of the display to another to view or select items that are not accessible from where you currently are. Thus physical navigation were treated as an result of having to access information and not an actual mean of accessing the information.

Based on this idea the aim were to develop and test interaction techniques that exploited users physical navigation in an attempt to make it easier to access information. The idea is based on the assumption that physical movement is something natural and that information about it is relevant for helping the user. I believe this assumption holds. In every day life we use ourself and our movement to get to things - we walk towards the kitchen sink to have a glass of water and we take a step back to get an overview of a painting. We employ these embodied resources to solve every day tasks. The idea is that this argument could also be applied to a virtual world where we would approach objects to inspect them closer or take a step back to get an overview. This thesis tries to uncover interaction patterns with user tracking that enables this kind of behavior.

With this close attention to the users position is should furthermore be possible to harness the value of this data in other ways. Therefore the goal of this thesis is also to take a look at information visualization in the context of user tracking. How can we exploit users' movement and position to enhance what is shown to the user in the virtual world - something that isn't feasible in the physical world.

The goal of this thesis is to open up the discussion of these subjects and to empirically test some initial prototypes that employs the techniques.

Part I

Related work

In the following sections previous work in the area of wall-size displays in general and interaction design and information visualization for wall-size displays in specific will be presented. The goal of this part is to provide an overview of the subject and lay out a basis for the understanding of the content presented later in the report.

3 Wall-size displays

As wall-size displays are becoming increasingly popular so has the subject as a research theme. A fair number of people are working on many aspects of wall-size displays and related topics. Studies show that most users continue to have display space that represents less than 10% of their physical workspace area. However, the trend is going toward having multiple and larger displays [30]. Generally two basic approaches to creating large displays exist:

- Wall-sized displays seamlessly created from multiple tiled video projectors or LCD screens.
- Large desktop displays typically consisting of multi monitor configurations with seams between the monitors used.

Throughout this report the primary focus will be wall-size displays, but the subject of the smaller large displays will be touched upon as it provides the start of the research area as well as important insight on user behavior and interaction design that can be transfered to wall-size displays.

Looking at single monitor use it is evident that increased display size improves performance and overall user preference. Simmons and Manahan examined productivity for Microsoft Office tasks (using Word, Excel, etc.) for monitor sizes form 15” to 21”. They found significant productivity benefits for the 21” monitor size in both task completion time and user preference. Several other studies have showed similar results, for instance [14] and [15]. In [13] Czerwinski et al. compared a 15” monitor to a novel 46.5” wide surface. Results of a user study with fifteen participants showed that users completed tasks 9% faster and reported greater satisfaction using the large display, $F(1,13) = 7.0$, $p = .02$.

In these early studies observations indicated that efficiency improvements were caused by reduced need for moving and managing windows as well as an increased opportunity of having access to context for a given task.

In 2005 Robert Ball and Chris North reported on a study evaluating the effects of tiled high-resolution displays on basic visualization and navigation tasks [3]. A large display with a resolution of 3840x3072 were compared to two smaller displays (1560x2048 and 1280x1024) and found to perform significantly better than the smaller displays. Qualitatively Ball and North observed that the use of the larger display is less stressful and creates a better sense of confidence than the smaller displays. According to the authors analysis this were primarily an effect of two features of the larger display. Firstly, the increased display size allowed for more of the data set to be visible at the same time thus aiding the users in remembering the spatial position of targets by providing increased context. Secondly, the larger display allowed users to avoid using the mouse and keyboard for navigation - instead users could physically move and turn their head to inspect regions near by.

In effort to evaluate even larger displays Shupp et al. compared user performance time, accuracy and mental workload on multi-scale geospatial search, route tracking and comparison tasks across one, twelve (4x3) and twenty-four (8x3) tiled monitor configurations [33]. The authors hypothesized that user performance would improve with larger displays due to having more context visible and possibility of physical navigation with head and body. Results of an between-subjects experiment with 40 participants showed that in general increased viewport size improved user performance, but that the results are task dependent. Furthermore it was observed that a decrease in virtual navigation and an increase in physical navigation correlated with user performance. Also the performance implications of curvature of displays were tested and results showed that curved displays improve performance by up to 30% over flat displays regardless of viewport size. Finally it was showed that user frustration is significantly less on larger display than on smaller.

Jonathan Grudin reports in [20] on a qualitative study of how users with multiple monitors arrange information. He found that secondary monitors are generally used for secondary activities related to principal tasks - i.e. for peripheral awareness of information that is not in the main focus, and for easy access to resources. Furthermore a second monitor improves efficiency in ways that are difficult to measure yet can have substantial subjective benefit for the user.

In [1] the authors report on an experiment with 32 participants comparing the relative performance gain of using one monitor to 24 tiled monitors. Evaluation was done for tasks such as navigating, target location and pattern search using a gyro mouse. Results showed that navigation tasks were performed 247% faster using the large display ($F(1,508) = 118.9$, $p < 0.01$), target finding increased by 205% ($F(1,762) = 38.18$, $p < 0.01$) and pattern searching improved by 150% ($F(1,90) = 3.53$, $p < 0.06$). Furthermore the experiment showed an average increase of 371% for physical movement from the one monitor to 24 monitors setup. Concludingly a linear regression of physical navigation to performance time with an R^2 of 0.858 were found showing that the performance of the tasks was highly correlated to the physical navigation exhibited by the participants. In addition it were observed that participants always chose to physically navigate before falling back to virtual navigation with the mouse.

Section 4 on page 13 reports further on a study where the effects of physical navigation and peripheral awareness have been evaluated as independent variables.

3.1 Technical considerations and descriptions

The area of large displays emerged in the early nineties with the introduction of LIVEBOARD in 1992 and CAVE in 1993 [18, 12], but didn't really gain momentum until the late nineties and the beginning of the 21st century. Early research in the area focused a lot on technical issues of large and wall-size displays due to the technical limitations and the price of screens at that time. Only in recent years have large high-resolution screens begun to become a common commodity - primarily due to their falling prices[1].

Although wall-size high-resolution displays are still not widespread, solutions such as projector arrays and tiled LCD panels are making the technology more available to the research community and the corporate world. Both of these approaches to wall-size displays have their benefits and drawbacks. Tiled LCD panels, compared to projector arrays, are easier to align and color correct, they are less expensive, they take up less space, but the screens are usually separated by bezels thus not having a continuous display area. On the other hand projector arrays offer seamless integration of multiple tiles and the display size is independent of the device size.

When Scott Elrod and colleagues introduced LIVEBORAD in 1992 they described their system as

> [...] a large interactive display system. With nearly one million pixels, [...], the Liveboard provides a basis for research on user interfaces for group meetings, presentations and remote collaboration. [18].

Although this system in size is far from recent work, such as the 100 megapixels of The Hyperwall [31], important observations, that are still valid today was made early on. For instance the article writes *For the person working at the Liveboard screen, the user interfaces of most workstations and notebook computers are inadequate.* [18, p. 606].

In 1993 Carolina Cruz-Neira and colleagues presented the CAVE, a surround-screen projection based virtual reality [12]. The system consisted of three rear-projection screens for walls and a down-projection screen for the floor thus giving the user the experience of standing in a completely virtual world. The CAVE gained a lot of attention and helped the research on the technicalities of large screens to gain momentum.

Patrick Baudisch and colleagues created a wall-size low resolution display with an embedded high-resolution display region in 2001 and tested it's usability in 2002 [6]. By using low resolution context area they created a cheap wall-size display for context+focus tasks such as working with multiscale documents. The system showed that advantages of wall-size displays such as the increased peripheral information provided, compared to small screens, can be achieved without expensive high resolution displays. Another more recent focus+context display consisting of three back projected displays are describe and discussed in [8].

For further reading on the technical solutions Tao Ni and colleagues have written an extensive survey of large high-resolution display technologies, techniques and applications [27].

4 Interaction design for wall-size displays

When creating wall-size displays a whole new set of issues become apparent compared to regular workstation screens. Factors such as viewport size, curvature and the users

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[1] In 1993 a 17" CRT-monitor was about $800 [35] - today a 24" wide-screen LCD-monitor, with a significantly higher resolution, can be acquired for less.

visual acuity becomes relevant to take into consideration when designing and testing the systems.

The sheer size of the display creates a new set of issues not thought of before - reaching objects far away, tracking the cursor and managing space and layout becomes issues that the system designers need to account for.

Tao Ni and colleagues identify ”Effective interaction techniques” as one of the top ten research challenges associated with large high-resolution displays. [27], but the challenge was realized much earlier. Swaminathan and Sato wrote in their 1997 paper:

> Perhaps the most succinct description of our experience with Prairie[2]. is that when we started, we thought of a large display as basically the same as a regular display, just larger! We no longer do so. We think that when a display exceeds a certain size, it becomes qualitatively different: different design issues come into play and interaction deign becomes full-blown environment design. [35]

A whole new set of interaction techniques was needed and thus this subject has been an area of substantial research since then. Similar insight are drawn from the field of *embodied interaction* which argues for the need to design interaction techniques that take advantage of embodied resources we contain. Paul Dourish defines embodied interaction as:

> interaction with computer systems that occupy our world, a world of physical and social reality, and that exploit this fact in how they interact with us. [16]

In other words, an interaction technique that takes advantage of embodied interaction principles take advantage of how people actually interact with the physical world. Similar to Swaminathan and Sato this points out that interaction techniques should not be designed in a closed framework, but should be full-blown environment design which can take advantage of peoples natural movement, gestures, etc. As an example a hammer becomes a natural extension of your body when you want to drive a nail into some wood. The hammer exploits the body’s embodied resources and interaction techniques and becomes an extension of your hand. In contrast an interaction device such as a mouse might be easy to use, but not natural. You can easily understand the mental model that moving the mouse on the table moves the cursor on the display in a similar way. However, the mouse is not natural because you must indirectly move the cursor on the horizontal plane (the table) to have it move in the vertical plane (the display). Using a touch-sensitive display on the other hand constitutes as embodied interaction as it is natural to point and touch where you want the cursor to go - there’s no need for an indirect mapping between your interaction and the result.

Ball et al. provides an overview of different interaction techniques and the pros and cons of each large display with special emphasis on embodied interaction and usability engineering in [1]. The following is a summary of the observations made by Ball et al.

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[2] Prairie was a virtual enterprise management and collaboration tool implemented using a large display

Pointing interaction A formative study evaluated a developed interactive pointer that precisely could point to any location on a large display independent of its location. A kindergarten class were invited to draw shapes and have fun on the display using the interactive pointer. The children were, without prior instructions, able to accurately point to the display by receiving instant feedback of the position by seeing where they were pointing. Experience showed that the children quickly leaned how to use the display and that the pointer seemed natural to them. However two main problems were observed. Firstly the cursor is only as steady as the users hand and secondly in order to change the state of the pointer (to change size or color) an additional device were needed.

Touch screens Touch screens are natural devices that are both easy to learn and easy to use. Experience show that precision with normal sized desktop icons can be problematic. Furthermore one of the largest drawbacks of using touch screens are fatigue - especially for the arms - when used for repetitive tasks.

Wireless 3D gyro mouse A gyro mouse is a mouse that can be used without a table and carried around freely. The gyro mouse is able to sense vertical and horizontal movement, but not forward and backward movement. In comparison to a regular mouse a gyro mouse allows for more natural interaction because the user doesn't have to map a horizontal plane to a vertical one. Thus one does not need a complex mental model as the cursor mimics physical movement. Though, the gyro mouse isn't as natural as a pointer since all movement is relative to the position of the cursor and not to where you are pointing. Similar to the pointing interaction the disadvantages of a gyro mouse is fatigue caused from not being able to rest your arm on a stable surface as well as the cursor only being as stable as your hand.

Head tracking interaction Head position and orientation can be used for interaction with a large display. A formative study comparing head tilt tracking, hand tilt tracking and two different mouse interaction techniques in tasks such as finding and comparing objects in maps were carried out. Results found that the hand tilt tracker was the most efficient in terms of both performance and user preference. The head tilt tracker was the worst in both metrics. User feedback explained that users among other things experiences that this technique drew their attention away from the display whereas hand tilt tracking allowed for free movement of the head while panning using the hand.

Evidence of the issues with fatigue and precision inherited in pointing interaction and the gyro mouse are further supported in [25]. Results of an experiment with 12 participants about selection tasks for a handheld trackball and a standard mouse show that the standard mouse is a factor two faster than the handheld trackball, $p > .001$. Finally, in a observational study, in a non-controlled experimental evaluation, Ball and North reports about the potential for physical stress and pain when using large screens. They argue that *if using a keyboard or a mouse for extended periods of time cause problems, then it is also logical that extended use with a large display may cause physical injury or discomfort to the neck.* [2].

For aiding users in keeping track of cursors on wall size displays a couple of techniques have been proposed. The *High density cursor* [5] employed temporal super sampling for helping the user with keeping track of the mouse cursor when using mouse acceleration. Users exploit mouse acceleration on large screens to traverse the area more quickly. Users performed Fits' Law targeting tasks up to 7% faster using the high density cursor. A follow-up project called *Mouse ether* [4] proposed a solution for the problems inherited in targeting with the mouse across multiple monitors by compensating for the distortion of the mouse path otherwise caused by bezels, gaps and resolution differences. Mouse ether was found to improve participants targeting performance by up to 28%.

Much effort has been put into developing interaction techniques for targeting tasks on wall-size displays. The difficulty with reaching distant targets on wall-size displays were already noted by Swaminathan and Sato in [35] who proposed three approaches to solving the problems: (a) direct manipulation using touch-sensitive-displays and laser pointers, (b) nonlinear mapping with sticky controls and (c) the dollhouse metaphor where the idea is to present a model of the display and the display objects and let manipulation with the model translate into manipulation with the larger non-model objects. Currently I know no significant literature that treat the dollhouse metaphor, but (a) and (b) are a commonly researched topic.

In [21] Guimbretire, Stone and Winograd describes a new interaction technique for direct pen-based interaction on a large display. The display called the *Interactive Mural* was tested with five groups in a digital brainstorming tool used by professional product designers. Users expressed positive experiences with the interaction technique and the large display for collaboration, specially noting the natural interaction technique and the seamless integration with the real world.

As a practical implementation of nonlinear mapping with sticky controls are the development of the *drag-and-pop* interaction technique [10]. *Drag-and-pop* is an improvement of the traditional drag-and-drop that provide users with access to screen content that would be otherwise hard or impossible to reach. During a dragging operation, drag-and-pop temporarily moves potential targets towards the user's current cursor location. By shortening reaching distances and leaving visual feedback so the user maintains a visual orientation of the content, the technique was shown to improve participants targeting tasks up to 3.7 times. A later study improved the design of this technique by combining the strengths of drag-and-pop and a technique called *push-and-throw* (see [22] for more details) into *push-and-pop*. Push-and-throw essentially extends the users reach by letting the user employ a throw-like gesture for targeting. Push-and-pop showed, in a within-subjects design with 12 participants, to perform the best of six different interaction techniques designed for extending drag-and-drop to wall-size displays ($p < .001$). *Vacuum*, a further development of *drag-and-pop* showed that the current interaction techniques for targeting and selection can be further improved, but not substantially. *Vacuum* performed on average faster than *drag-and-pop* and direct picking in multiple target selection, but not in single target selection [7].

Ball and North analyzed the effects of physical navigation on large scale visualizations and found that opportunity of increased physical navigation is more critical to improving performance than increased field of view [29]. By carefully testing the two independent variables peripheral vision and physical navigation in a 2x2 experimental design with 24 participants and performing two-way ANOVA on the results they could identify significant performance gains with increased opportunity of physical navigation, $F(3,956) = 4.72$ and $p < 0.001$. These results were based on a combination of navigation, comparison, search and estimation tasks in a map application with visualization of houses for sale. Although physical navigation was observed to be the main effect of efficiency gains evidence indicates that a combination of both physical navigation and increased field of view is the best combination. Additionally Ball and North observed that behavior was most affected by physical navigation, and participants were observed to employ different strategies for solving tasks when using either physical navigation or virtual navigation. This difference in behavior was not observed between the different levels of the peripheral vision independent variable.

5 Information visualization for wall-size displays

Although the research area of information visualization is immense and has been a subject of interest for a long time, very little research focuses on the scalability of information visualizations. Existing techniques for information visualization have not been studied in the context of large displays, and in what little research actually exist the focus have primarily been on the technical implementation as opposed to the usability implications of scaling the visualization techniques.

Visual scalability were defined by Eick and Karr in [17] as being the ability of visualizations to effectively display large amounts of data. Furthermore they decomposed the issue into the factors affecting it: human perception, the visual metaphor and the display as well as algorithms and computation. As for human perception one author has argued that a 4000x4000 pixels display should be adequate for any visual task because this resolution most effectively maps ”brain pixels” to screen pixels [36]

In [37] Bin Wei and colleagues presents a large display wall at AT&T Global Networks Operations center which uses a tool set called *Swift-3D*. This provides support for data exploration, integrating large-scale data visualization with querying, browsing and statistical evaluation. They observed that especially geography is one of the few representations that worked well for large scale visualizations - which in their case was visualization of networks.

For visualization on large tiled displays mainly three implementations stand out: *Vol-a-tile*, an interactive tool for exploring large volumetric data [32], *JuxtaView*, a cluster-based application for viewing ultra-high-resolution images [23] and *Lambda Table*, a table consisting of tiled displays with direct manipulation for visualizing maps of earth and the galaxy [24]. However, none of these studies evaluate usability, but instead focuses on technical performance and implementation. If the users experience better performance, memorability or accuracy remains uncertain.

A paper explicitly discussing scalability is the presentation of *FacetMap* by Greg Smith et al. in [34]. FacetMap is an interactive, query-driven visualization that uses visual metaphors for both input and output. Although the main focus isn't scalability or large visualizations the authors briefly touches on the subject. Their main insight is, however, of technical nature, stating that there's a need for methods of dynamically crafting large visualizations. Contrary to visualizations on smaller scale, hand crafting a large visualization are highly time consuming and infeasible. The technique used for FacetMap allows for effortless scaling to displays of different sizes.

Another such application is *SimulBrowser* presented in [30]. SimulBrowser is a web browser that utilizes all displays in a tiled setup. For searches the application shows the top results on separate displays and uses a last display for snapshots of the pages the user are interested in. When a user sees a page of interest in the search results she clicks it and a snapshot of the page is moved to the last display. Then the user can move on to additional search results and thus maintain a collection of interesting pages for further study. However, the application were not tested empirically and it's impact on usability measures remains unknown.

At the time of writing, the only paper I am aware of that treat the subject of scalability of visualization in depth are *The perceptual Scalability of Visualization* by Beth Yost and Chris North [28]. Contrary to the other papers discussed Yost and North evaluates scalability empirically in a controlled setup. The authors pose that:

> [...] as larger displays are used for visualization, the scalability limit may be shifted away from the graphical scalability limits imposed by the number of pixels and toward human limits.

An obvious example of this is when display size increase more than the human eye can view or when the displays becomes larger than realistic amount of physical movement can reach. On this basis the authors pose three important questions:

- When the screen isn't the limiting factor, just how much data can a person effectively perceive?
- As more data is shown whit increasingly larger displays, do we hit a breaking point, the limits of visualization?
- And how will visualizations for large displays need to fundamentally differ from visualizations on desktop displays? I.e. how are basic visualization design principles different on large displays?

In [28] the authors begin to answer these questions by conducting a user study of three different visualizations across two different display sizes - a 2Mp display and a 32Mp display. The study employed a 2x3x7 mixed design with independent variables being display size, visualization design and task type. Dependent variables were task completion time, accuracy and subjective workload. For the experiments data from 1976 to 1989 on homicides in demographic categories such as age, race and gender were used.

Three different visualizations were tested. Two of the visualization designs used a space-centric approach by overlaying the data on a large map. The last used a attribute-centric approach, meaning that each attribute of the multidimensional data were on a separate spatial structure - this is analogous to the small multiples principle. The tasks the ten participants had to solve were combinations of task types categorized as detail, overview, time, attribute and space.

The results showed that the designs tested were perceptually scalable. That is, scaling did not result in an increase in task completion time or a significant decrease in accuracy. Accuracy only decreased from 95% to 92% and despite a 20x increase in data only a 3x increase in task completion times were observed. Furthermore the user preference and cognitive workload results indicated that graphical encoding seemed to be more important with less data on a small display and that spatial grouping are more important with more data on a large display.

6 User tracking

User tracking systems exist at a wide range of granularities. From eye tracking, head tracking, gesture tracking to full user tracking with the possibility of tracking multiple users. Unfortunately not much research or readily available systems exist for the latter - full user tracking. In this section I will not explore the subject of eye tracking, head tracking or gesture tracking as it is outside the scope of this thesis. However I will report on lessons learned while developing the final system for use in the user study described later in this report. Several systems were tested until a working solution were reached. These systems include tracking based on RFID tags, a system based on Nintendo Wii remotes and finally web camera tracking.

Ubisense Original plans for the project intended to use a commercial system called Ubisense for the user tracking. Ubisense is a real time location system in three dimensions. The system uses ultra-wideband radio frequency sensor nodes for locating active RFID tags in three dimensions. The advantages of such an system is precise location (once calibrated) independent of environment factors such as light, users clothing, height, etc. Furthermore the shipped software provided an easily accessible integration into client applications using a Microsoft .NET 2.0 API. Officially the system promises an accuracy of 15 centimeters at 10Hz, but actual testing of the system showed an accuracy of only 50 centimeters. This is further supported by the evaluation in [11]. Furthermore the specification promised information about yaw, pitch and roll of the tags, but the programmers .NET API shipped with the system did not deliver such data. The system required careful setup with precise measurements of node locations and a thorough calibration process. But despite several attempts at improving the system it was finally deemed to imprecise to for this project. Because of a limited floor area and display size available for the experiments, 50 centimeters accuracy would account for only 4.7 distinct positions.

Nintendo Wii remotes As a replacement for the Ubisense system a solution using a Nintendo Wii remote were tested. The Nintendo Wii remotes are integrated with an infrared camera that can detect infrared light sources such as infrared LED's. By having two distinct light sources the system are able to compute the position of the light source within the viewport as well as the source's rotation and distance to the camera. Drawing inspiration of the head tracking projects by Johnny Lee[3] a system using the Wii remotes and a managed library for the remotes [4] a test setup were implemented.

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[3] Head Tracking for Desktop VR Displays using the Wii Remote: `http://www.cs.cmu.edu/~johnny/projects/wii/`

[4] Managed Library for Nintendo's Wiimote: `http://www.codeplex.com/WiimoteLib`

However, early tests showed that the limited view angle of the Wii remote camera would make detection within a large area infeasible. Because of the limited viewing angle the remote had to be located further from the user than the available experiment location allowed for. Furthermore changes in users' angle to the camera (when rotating to see the opposite edge of the display) required integration of several remotes to maintain accurate position. Although this solution in theory could be implemented time constraints for the project asked for a less time consuming solution.

Web camera tracking The final solution uses a ceiling mounted ultra-wide angle web camera for tracking. The advantage of the ultra-wide angle lens, as compared to the Nintendo Wii remotes, is that it can cover a larger area in shorter distance. Two different approaches were tested before a suitable one were found. Firstly a basic motion detection algorithm were used. The algorithm basically finds differences between a current image and a reference image to detect what areas have changed. However, this technique detects all changes in the image and for a single user this includes their body as well as arms and legs. As an result the bounding box (and thus its center) for the detected user would change if users moved arms and legs and this were not acceptable for this project. To prevent this change in size an object of somewhat static size were needed. As a solution a color filter were used to filter out any other colors than the color of a hat the users were asked to wear. This way the tracked object would stay the same size independent of users posture. More details about the final solution can be found in section 10 on page 38.

Part II

Possible approaches to interaction design and information visualization in the context of user tracking

This part of the report will present and discuss possible approaches to interaction design and information visualization in the context of user tracking. The sections will suggest ways of implementing panning, zooming and dimension mapping for a user tracking system. Furthermore the section about information visualization will point out some possible ways of taking advantage of the known position of users. The goal of these sections is to provide an overview of fundamental approaches to the subject, and not to provide an exhaustive list of all possible designs.

7 Interaction design with user tracking

In this section I explore the possibilities of utilizing the knowledge of users position and movement as a primary mean of interaction in a virtual world.

Throughout this and the following sections some common basic terms will be used and thus there is a need to define them properly here. Figure 1 on page 22 shows an illustration of the physical and virtual spaces. The physical space is the space in which users actually move and exist. The virtual space is the abstract space wherein the visualization and its data resides. Both spaces are defined in three visible dimensions x, y and z. The coordinate systems are aligned as shown in Figure 1 on page 22 - i.e. the physical y-axis, y_P, corrosponds to distance from the display, x_P is the sideways location in front of the display and z_P is up and down in the physical world. The virtual space is treated as a three dimensional world as if we looked down into a box from one of it sides. x_V is sideways location, y_V is how far into the box objects are and z_V is the distance from the edge we are standing at and the opposite edge.

7.1 Mapping between dimensions in virtual and physical space

A central issue with the mapping between dimensions in virtual and physical spaces in a floor-to-wall-framework is the loss of a dimension. The problem arises due to the nature of human beings as earth-bound creatures that can only walk on a solid foundation. We are in practise stuck to the ground and can thus only move in two dimensions - along the x-axis or y-axis in a regular coordinate system[5].

Although both areas, the floor and wall, are both two dimensional in the physical world the fact that the wall is a viewport into a virtual world enables it to mimic three di-

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[5] One could argue that human beings do move in a three dimensional space as we can walk up stairs, ladders or the like. But if one look at a single point we cannot change our position along the z-axis permanently unless we change the foundation upon which we stand. Temporarily, though, we can do things like jump and bend our knees. The use of external aid such as a lift are not feasible in this context.

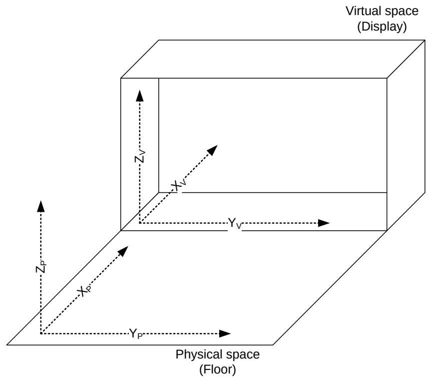

Figure 1: Definition of coordinate systems in physical and virtual space.

mensions. Thus we have a physical world (the floor) with two dimensions and a virtual world (the display) with three dimensions. This loss of a dimension causes problems because no trivial direct mapping between all dimensions exist. The following sections will suggest ways of overcoming this problem.

Furthermore the mapping is complicated by the two spaces being oriented differently. The virtual space is oriented perpendicular to the physical. This in effect complicates the mapping between axes because only a trivial mapping exists along the *x*-axis where the two space planes intersect.

7.2 Panning

Panning refers to horizontal or vertical movement of whatever displayed relative to the viewport - i.e. moving the visualization along the *x* or *y* axes in a regular coordinate system.

7.2.1 Horizontal panning

Horizontal panning is the most easy to mimic with user tracking. A direct mapping between the tracking area and the display is possible by letting the tracking area 's *x*-axis correspond to the visualization's *x*-axis. Thus, when the user moves to the left when facing the display, the visualization pans to the left, as seen in Figure 2 on page 23.

In effect - if the mapping is linear - this technique would cause the object in front of the user to stay there even if she moved. Such a property could for instance be useful for items often needed by the user such as tools, menus or some reference object used for comparison.

A modification of the direct mapping between the two *x*-axes could be a inverse relationship between the two. Instead of letting movement of the user in one direction correspond to movement in the same direction of the visualization the relationship could be reversed. I.e. if the user moves left the visualization would move right, as

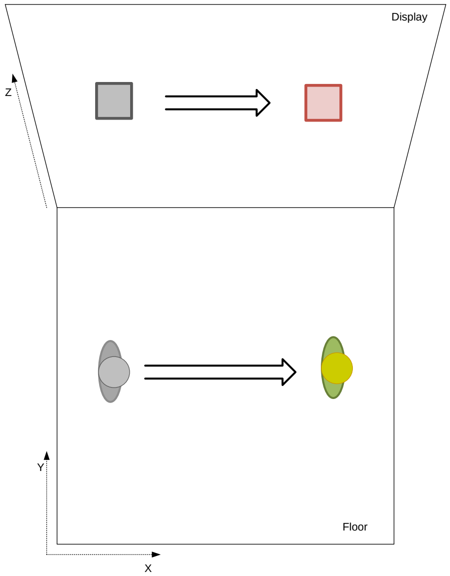

Figure 2: Horizontal panning with user tracking.

shown in Figure 3 on page 24. The user would experience that objects in the direction she walked would come towards her on its own as to meet the user halfway.

This would in effect cause the physical distance that the user needs to walk to be reduced as compared to if the object stood still. This inverse mapping can be useful for interacting with virtual spaces that are larger than the physical space.

7.2.2 Vertical panning

Contrary to horizontal panning, vertical panning is somewhat more tricky due to the issues described in section 7.1. Among the three dimensions in the virtual space the vertical axis (z-axis) is the hardest to map to the physical space because it spans vertical movement which humans cannot traverse without aids. One possible solution is to create a y_P to z_V mapping as if the virtual place were rotated along the x-axis to be parallel to the physical space. This is depicted in Figure 4 on page 24.

However this would result in a visibility biased solution where the user cannot see details a closely in the bottom half of the virtual space as in the top half because she would be further away from the display.

7.3 Zooming

Movement along the virtual y-axis is considered zooming as it changes the distance to what was previously the xy-plane in the physical space. Like horizontal panning zooming is easily mapped from physical space to virtual space.

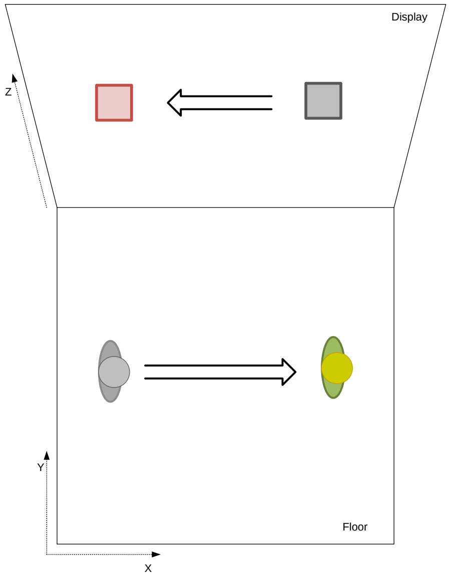

Figure 3: Reversed horizontal panning with user tracking.

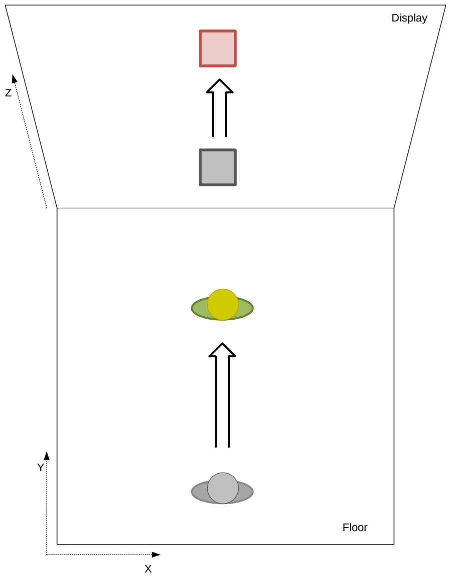

Figure 4: Vertical panning when y_P is mapped to z_V.

A y_P to y_P mapping would mean that walking closer to the screen would increase zoom and walking further away would decrease zoom, just as showed in Figure 5 on page 25.

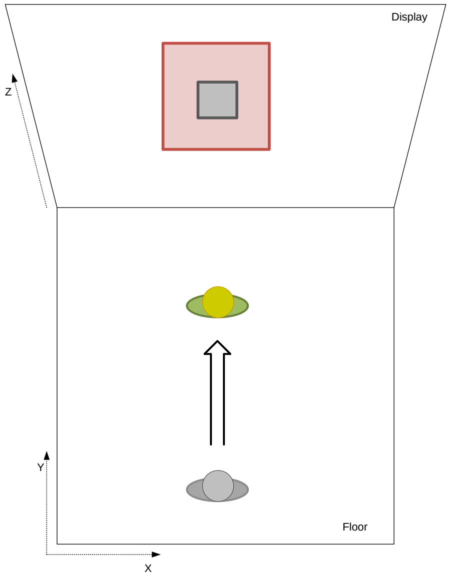

Figure 5: A zooming technique where walking towards the display zooms in and walking backwards zooms out.

This mapping would seem natural as it is just an amplification of what is experienced in reality - i.e. walking closer to a object enlarges it in your viewport. Furthermore this interaction technique would support users behavior when viewing large surfaces where people tend to walk further away from the surface as to get an overview of it.

7.4 Span of dimensions in virtual and physical space

An issue that arises when talking about a mapping between dimensions in a physical world and a virtual world is how to handle the differences in the span of each dimension. Although potentially infinite, physical space in this context are a very limited space. Not only due to how large it can be on earth, but also in how far edges of it can be while still being able to see the display. In contrary the virtual space can be limitless - only technical issues effect how large we can make them. Although traversing a large virtual space can seem impractical, it is possible to design interaction techniques that makes the task easier, whereas traversing of physical space is limited to the capabilities of our human legs and eyes.

Below are two suggestions to overcome the problem described. This section only discusses solutions that does not conflict with the linearity of relationships between dimensions. Such solutions are described in section 7.5.

7.4.1 Hot zones

One way of overcoming the differences in dimension span between the physical space and the virtual space are the concept of hot zones.

Hot zones in general are regions in the physical space that triggers some event when the user enters it. One application could be to implement automatic scrolling at the edges of the physical space. An example of this is shown in Figure 6 on page 26.

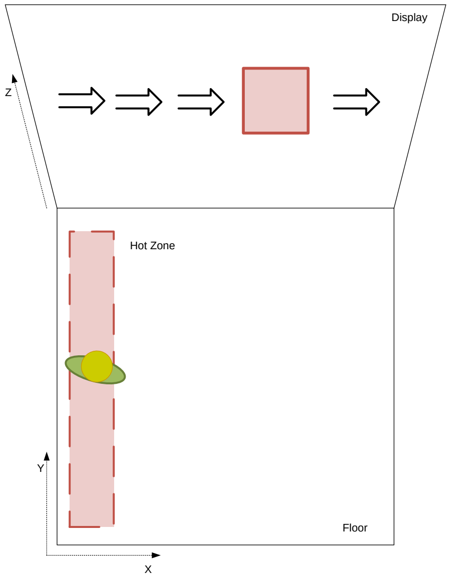

Figure 6: Automatic scrolling of the visualization using a hot zone.

Entering a hot zone causes the visualization to scroll automatically in a given direction - in this case to the right. This enables the user to get access to more of the left part of the visualization than the physical space can provide. When the user leaves the hot zone the automatic scrolling stops.

Although Figure 6 shows the hot zone as a discreet area it is also possible to implement it as a gradual transition. I.e. if used for scrolling the speed of the scrolling could gradually increase as the user moves further into the zone thus letting her experience a smooth transitions between the two methods of interaction.

7.4.2 State dependent tracking

Another solution to the mentioned problem is to use a technique that employs state dependent tracking. By letting the user explicitly express when and when not movement should be tracked it is possible to employ a move-reset-move technique where the user activates tracking, moves until she runs out of physical space, deactivates tracking, moves back to her original position and then repeats the procedure until the target is reached. This is similar to how you would lift a mouse and put it down in another place when you run out of space on a table. The technique is depicted in Figure 7 on page 27.

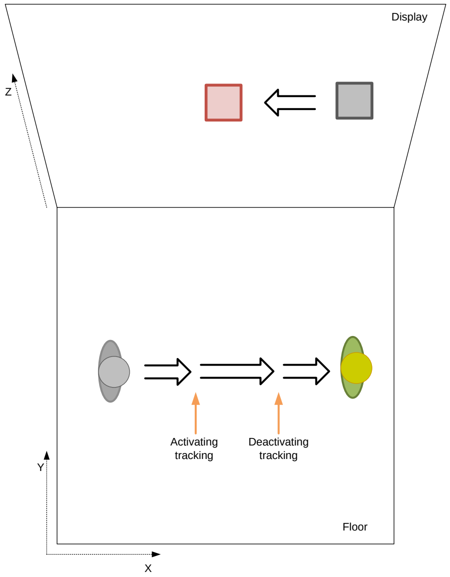

Figure 7: Example of state dependent panning where the visualization only moves when the user activates sideways tracking.

A side effect of this technique is that the user has full control over when her position are tracked and thus when the visualization would react on movement. This gives the user the opportunity to move freely around without having to worry about the effect on the visualization. However this technique will force the user to move a lot if the virtual distance between her original position and the target is big.

7.4.3 Proximity selection

As opposed to interaction techniques that are used to traverse distances alone of one or more of the axes proximity selection in the context of user tracking is about using the users position to interact with objects in the visualization.

Panning and zooming which have been discussed in the previous sections both created a mapping between a point in the physical space and a point in the virtual space which could be used to manipulate the current viewport. Instead of such a mapping the users position can be used for defining a relationship between the user and the objects represented on the display.

Figure 8 on page 28 illustrates an example where the users position indirectly selects an object to show detailed information about.

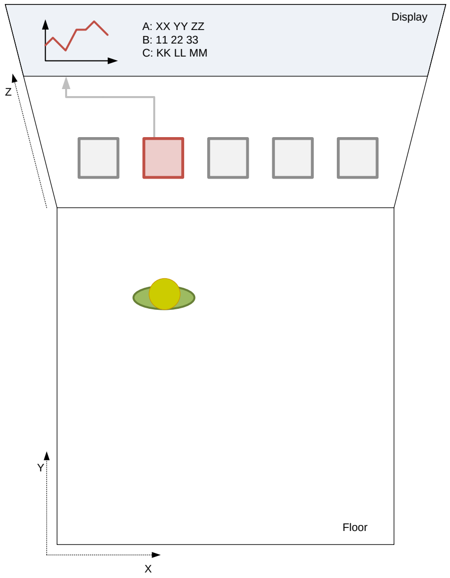

Figure 8: Example of proximity selection based on the users position which shows additional information about the selected object.

This technique could be useful for exploration of data where users naturally walk towards objects of interest to them to get more information about that object.

7.5 Mapping functions

In the previous sections mainly proportional (and inverse proportional) linear mappings between axes have been described. In such cases a movement in one direction in physical space would cause movement of the virtual space in a distance proportional to the physical movement. In this section a few other possibilities will be explored.

Acceleration A well known techniques from computer mice is the use of acceleration of the cursor. This creates a mapping that is dependent on the duration of a movement. The longer the movement lasts the more (or possible less) is the tracked movement amplified before mapping it to the virtual space, possibly with some upper limit on the speed. This way the user can traverse longer distances when walking the breath of the display while maintaining fine grained control when just moving in front of an object.

Speed dependent Instead of just examining from where to where the user moved a temporal aspect can be included so that the speed of the user is known. This information can then be used to manipulate the mapping from physical to virtual space.

An example of it's use is the reduction of the effect on virtual space in a inverse relationship between axes. Assuming that the user could get confused by how quickly an object comes towards her it would be helpful to reduce the speed of the object when the speed of the user increases. Although this would increase the total physical distance between virtual objects it could possibly put the user in better control of the interaction and when targets are reached.

Position dependent The previously mentioned techniques are both independent of the location of the user. However, this information could be used to manipulate mappings. In this way, each possible position along a given axis would yield a given amplification of the physical interaction.

An example could be to have the x-axis be transformed though a upside down bell-shaped amplification function. This would cause the mapping between the physical space and the virtual space to be amplified more along the left and right edges of the physical space. In effect this would allow the user to pan fast when going near the edges while having a slower mapping around the center to have more control over movements. In general this technique is similar to that of the graduated hot zones as described in section 7.4.1.

Another technique could be to employ a exponential transformation along the y axis when zooming. This could for instance cause the zooming to suddenly increase rapidly as the user moves to the back of the tracked area. This could help the user by zooming out to an overview look of the visualization.

8 Information visualization with user tracking

Information visualization is the discipline of creating visual presentations of abstract information spaces and structures to facilitate faster understanding and digesting.

In this section we explore possible approaches to information visualization on large displays that take advantage of the user's position to create a relationship to the visual representation. Most of the suggestions laid out in this section operate under a basic mapping of the physical space and the virtual space where $x_P = x_V$, $y_P = y_V$ and the mapping of z_P to z_V is undefined. The lack of a mapping from z_P to z_V causes an issue when we try to define the focal point of the user. Because the user cannot move freely along the z-axis the focus point cannot be freely placed along that axis. To overcome this issue we can define the focal point as either a point at some predefined level along the z-axis (at eye level for instance) or as the whole of the z-axis. The two possible definitions are illustrated in Figure 9 on page 30

In the following examples the focus point will mainly be defined as a pint at eye level. However the examples are easily translated to the case of the focal point being the whole of the z-axis.

As this section discusses the concept of information visualizations that utilize the users position, and not information visualization in general, we will primarily focus on the abstract concept of lenses. Lenses are an viewport overlaid on the original visualization that manipulates the representation in some way; just as a magnifying glass enlarges the objects beneath it.

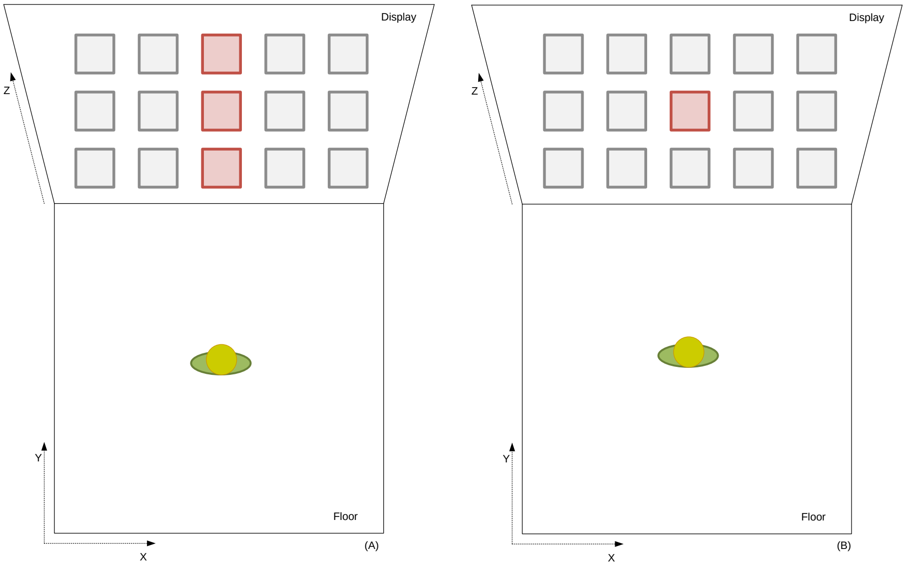

Figure 9: (A) Focal point defined as all of the z-axis and (B) as a point at eye level.

8.1 Distortion visualizations

Distortion visualizations are techniques that manipulate and distort a representation of data without changing the semantic representation itself. In other words the objects in the visualization are scaled, skewed, rotated and transformed.

8.1.1 Fisheye view

Fisheye views is a visualization technique in which information in focus is clear and of normal size, while information surrounding it is progressively miniaturized and distorted, thus allowing presentation of more context within a limited screen size. The focus of such a fisheye view could be defined by the users location, thus giving content close by special emphasis and detail. Figure 10 shows such an fisheye view with focus defined by the users location.

Advantages of such an visualization is the special emphasis on the content in focus while the user is still able to maintain context.

8.1.2 Perspective correction

As described in [26] differences in perspectives on large or multiple displays can make it hard for users to reach targets precisely and to view information properly thus resulting in a efficiency reduction. A possible solution is to implement perspective correction which compensates for the different view angles from user to positions on the display. This technique is illustrated in Figure 11 on page 31.

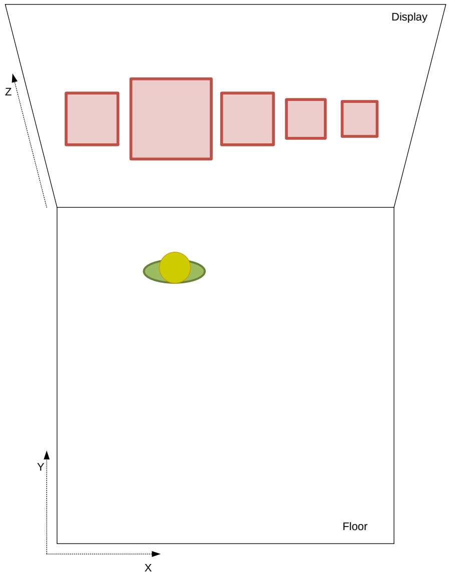

Figure 10: Fisheye distorted view of objects on a wall-size display with focal point being the users position.

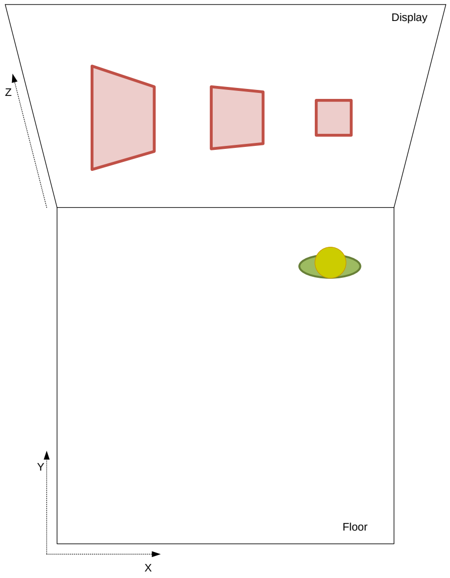

Figure 11: Perspective corrected objects on a wall-size display.

Although it causes a reduction of the visible content (due to scaling of objects), by employing this technique users are supported in their simple embodied interaction techniques such as turning the head. The benefits of this technique increases as the users distance to the display decreases. At the far back edge of the physical space the benefit would fade as compared to when the user is close to the display where the widest possible angle is quite large.

A recent study showed that perspective correction in a multi-display environment significantly and substantially (8% to 60%) improves user performance [26].

8.1.3 Distance correction

As a simple version of perspective correction distance correction employs basic scaling of the objects based on their distance to the user. This is illustrated in Figure 12 on page 32.

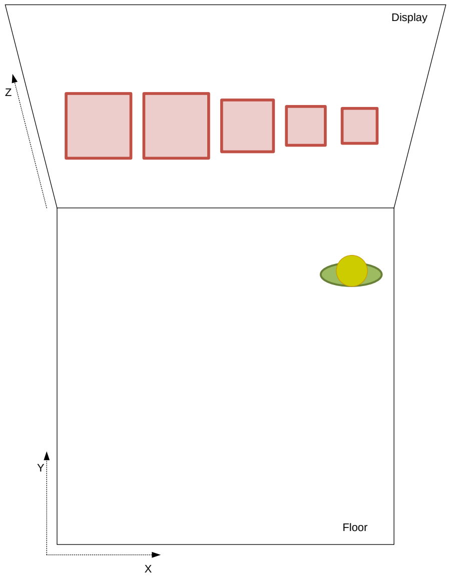

Figure 12: Objects on a wall-size display corrected for distance to the user.

Although the technique doesn't compensate for perspective distortion it does provide a compensation for object size caused by different distances. By enlarging objects that are further away legibility and visual acuity are maintained independent of the users position. As with perspective correction the benefit of this technique are greater the closer the user is to the display because the objects relative difference in distance are increased.

8.2 Semantic visualizations

Where the distortion visualization does not change the actual representation of information, semantic visualizations uses the context of the information to expand, simplify or otherwise change the representation as seen by the user.

8.2.1 Semantic zooming

With semantic zooming an objects representation is changed relative to the level of magnification. This is well known from maps, where cities change from small dots to views of the actual roads and houses. Using this technique on other data can help maintain a simple overview of the data regardless of how it is viewed - for instance by ensuring constant information density. An example of this in the context of user tracking is shown in Figure 13 on page 33.

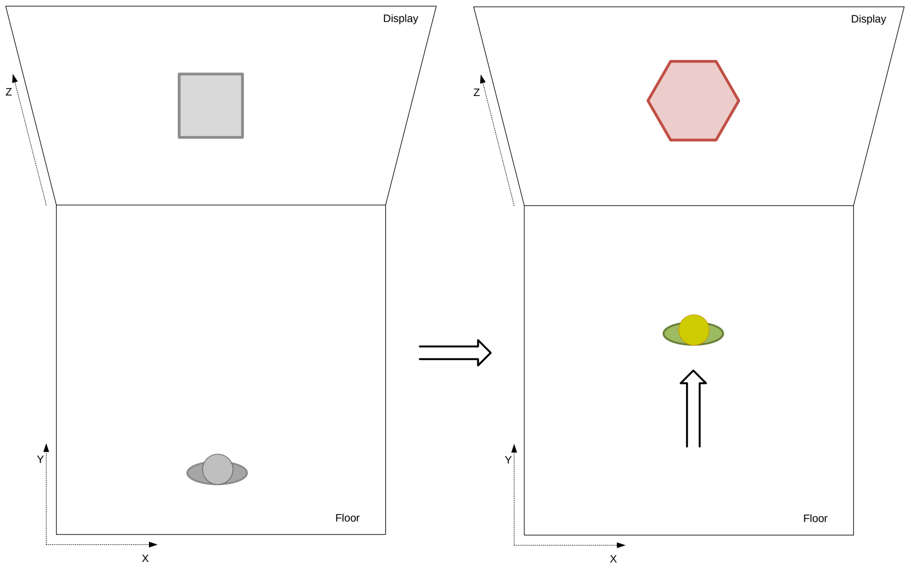

Figure 13: Example of semantic zooming with user tracking. The closer the user is to the object the more details are shown.

Mapping the users forward and backward movement to changes in zoom level would be a natural approach; when the user moves closer to the screen more detail are shown and the abstract representation becomes less relevant than a more detailed representation. This technique would support users in getting an overview of the data when standing as far from the display as possible, just as you would do when wanting an overview of what's written on a black board.

8.2.2 Information lenses

Another approach for semantic changes in representation is information lenses. As a magnifying glass distorts the information below, an information lens changes the shown information when the lens is overlaid. A wide range of information lenses are possible, but their design depend highly on the context in which they are used. Lenses can show additional information, filter out objects, change representation and much more. Figure 14 on page 34 shows an example of an lens that show additional information about objects.

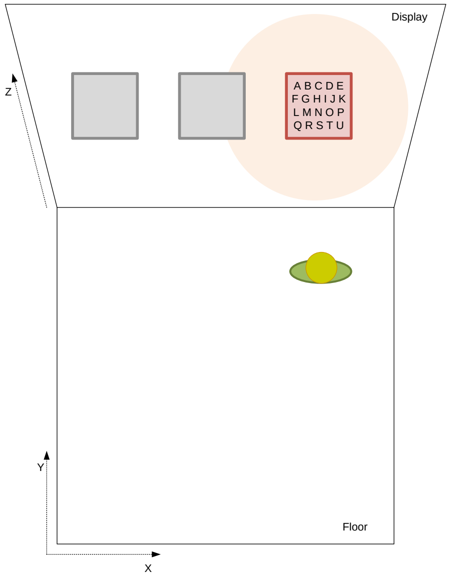

Figure 14: An example of an additive information lens in front of the user.

Some examples of information lenses in the context of a large map follows. A basic approach would show more information about the objects in front of the user than objects further away. For instance showing descriptions of land marks. Another approach would be to overlay a continuous layer of information such as a heat map of pollution. To support explorative tasks another approach is to show related information about the objects in the users focus. Such as restaurant reviews, public events, etc.

Instead of adding information it is possible to reduce the information density with a information less. This could be useful to filter out houses that are too expensive in a overview of houses for sale or to remove road names.

Finally as opposed to removing or adding information, the lens could simply replace the information. This could be used to compare maps created in the past and in the present or to view information about the underground.

Part III

Empirical study and results

The following sections report on the empirical study carried out to comparatively test two user tracking approaches with a regular approach. Firstly, the chosen approaches will be described and discussed followed by a description of the technical hardware and software implementation. Then the experiment design will be presented including hypotheses, procedure and metrics. Finally a descriptive data analysis will be carried out and the results will be discussed and interpreted.

9 The chosen approach

As described in section 8 and 7 the possibilities for interaction design, information visualization and combinations hereof for wall-size displays are endless. In this section I will describe the chosen approach for testing in an empirical study.

The data set and it's visualization used for the experiments are a social network of families and family members with three levels of data - family names, names of family members and details about each family member. The social network was visualized as nodes connected by lines indicating relationships. The data set is described fully in section 9.3.

The experiments consisted of three parts. One using a regular gyroscopic mouse, named regular interaction , and two using user tracking named position interaction and motion interaction of reasons made clear in the following sections.

The choices laid out in this section are primarily reached by a iterative design process with pilot tests. Different approaches were explored and the seemingly best ones were selected for further study.

9.1 Interaction design

Aiming primarily to focus on understanding if and how user tracking works for interaction two different approaches was chosen. The approaches differed in a couple of ways (described later in this section), but also had a identical design at some key aspects of the interaction.

Firstly, both approaches employs a inverse mapping of the x-axis from physical space to virtual space as described in section 7.2.1 on page 22. This means that if the user moves to the right the nodes in the network will move to the left thus shortening the physical distance that have to be traversed in effort to traverse the virtual distance. This allows the user to get access to more of the virtual space than the physical space immediately allows for. Pilot tests showed this to be a natural way of interacting with the network for the users.

Secondly, both approaches utilized the physical y-axis for zooming - i.e. creating a $y_P = y_V$ mapping as described in section 7.3 on page 23. Thus if the user walked closer to the screen the zoom factor would increase and objects get larger. Pilot tests showed that this was the most natural way of interacting. A $y_P = z_V$ mapping was also tested, but as anticipated users had a hard time understanding the technique as well as viewing the whole screen properly when being close to it.

Finally, both approaches used the scroll wheel of the mouse for traversing the virtual z-axis. This choice were made on basis of the discussion in sections 7.1 and 7.2.2. An earlier choice about using the mouse for selecting answers to tasks (this will be described in section 11.5 on page 50) required the experiment participants to have the mouse in their hand at all times so using it for vertical panning seemed like the best approach.

Furthermore both approaches used a amplified proportional mapping function for all axes, meaning that a moved distance D_P along an axis in the physical space would result in the same distance moved in virtual space corrected by some constant C so that $D_P = cD_V$. A pleasant[6] value of this constant was reached during the iterative design process. The reached value of c meant that the width of the physical space were larger than the width of the visualization in the virtual space thus creating a need for a method of accessing the proportion of virtual space not reachable with direct mapping.

position interaction The first user tracking approach to interaction design were chosen to include hot zones (described in section 7.4.1 on page 26) for automatic scrolling as well as state independent tracking.

To allow the users to access the virtual space not directly reachable via direct mapping two hot zones were placed along the left and right edges of the tracking area . The width of the hot zones were 10% of the width of the tracking area each which were wide enough for the users to activate them and keep them activated. The hot zone on the left would cause the network to automatically scroll right at a predefined speed. To prevent unintentional activation of the hot zones when users were near them a delay of two seconds were implemented. To indicated that the user had entered a hot zone a yellow arrow in the direction of scrolling were displayed. When the delay had passed the arrow would turn green and the scrolling would begin. An illustration of the hot zones and the indication arrow are shown in Figure 15 on page 37

Furthermore tracking along all axes were enabled at all time thus employing a state independent interaction design. This meant that the interaction were coupled with the users position - in the hot zones and in the rest of the tracking area - and hence the naming.

motion interaction Pilot tests showed that some users had trouble controlling horizontal movement and the activation of hot zones. Thus a second approach avoiding these issues were chosen.

This approach employs state dependent tracking as a main feature. As only horizontal panning seemed to cause issues the state dependent tracking were only implemented in the mapping function between the x-axes. As users were already required to hold the mouse in their hand at all times it was chosen to use the right mouse button for enabling and disabling horizontal tracking. Tracking were only performed when users pressed the button.

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[6] I.e. a level where the reaction seen on the display were not too fast and not too slow

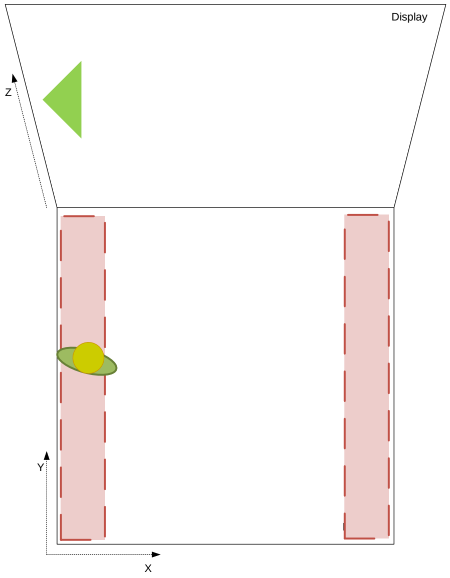

Figure 15: Position of hot zones and indication arrow for position interaction .

For users to access the proportion of virtual space not accessible via direct mapping users were required to use the move-reset-move technique described in section 7.4.2 on page 26.

The choice of using state dependent tracking meant that users movement, as opposed to their position, were the main factor in interaction with the visualization - hence the name motion interaction .

9.2 Information visualization

As mentioned earlier the primary focus of the empirical study will be the use of user tracking for interaction design. Therefore a basic approach for information visualization that employs user tracking has been chosen.

A key insight drawn from the pilot tests and the discussion of possible interaction techniques were the distortion of perspective and size of objects when the user is close to the display. Because of this a basic distance correction, as described in section 8.1.3, were implemented. In effect objects were equally visible and legible independent of their distance to the user and the users distance to the display.

Furthermore zooming were chosen to implement semantic zooming, as described in section 8.2.1. This choice were primarily made to support the empirical study. By having discreet levels of detail tasks could be crafted to require the participant to find answers at a predefined distance from the display. Furthermore a somewhat limited height of the tracking area would cause a continuous zooming of details to be too fast and impractical for the user if significantly different levels of details were wanted. The different levels of the semantic zooming are described in greater detail in the following section.

9.3 Data set

For the experiments an artificially created social network was chosen. The data set consist of a large set[7] of families with five family members in each totaling at 485 to 500. The information visualization created for the experiments uses semantic zooming with three levels to show progressively more details about families and family members as to user zooms in. The furthest away only the families represented by circles and family names are shown (Figure 16 A). Additionally, families are connected to other families with lines. On the mid level family members and their full names are shown as rounded rectangles (Figure 16 B). On the closest level a set of details about each family member is shown (Figure 16 C).

The last and first names were chosen from lists of the most used names in the United Kingdom and the United States of America. Full names were constructed by randomly choosing last and first names. Details about family members were a selection of everyday terms. Values for each attribute were randomly assigned. The list below shows the chosen attributes and their possible values.

- Number of children (0-3)
- Income ($20.000 - $120.000)
- Job title (Cashier, Accountant, Programmer, Cab driver, Pilot, School teacher, Architect)
- Height (150 cm - 200 cm)
- Car (No car, Chrysler, Ford, Lincoln, Camero, Chevrolet)
- Vegetarian (Yes, No)

This data set has been chosen because of its familiarity to people. Even though they might not be used to see visualizations of social networks, the concept of social networks, families and family members are well known. This choice ensures that basically everybody could become an experiment participant in the empirical study.

10 Implementation

The following section describes the technical aspects of the hardware and software used for carrying out the experiments.

Contrary to initial plans for the project the technical implementation proved to be a massive undertaking. This was mostly caused by not having access to the systems that were originally planned to form the technical foundation for the project. This in turn lead to the need for a custom made solution.

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[7] 97 to 100 families ($21x5$ nodes with a few unconnected nodes removed) with each five family members

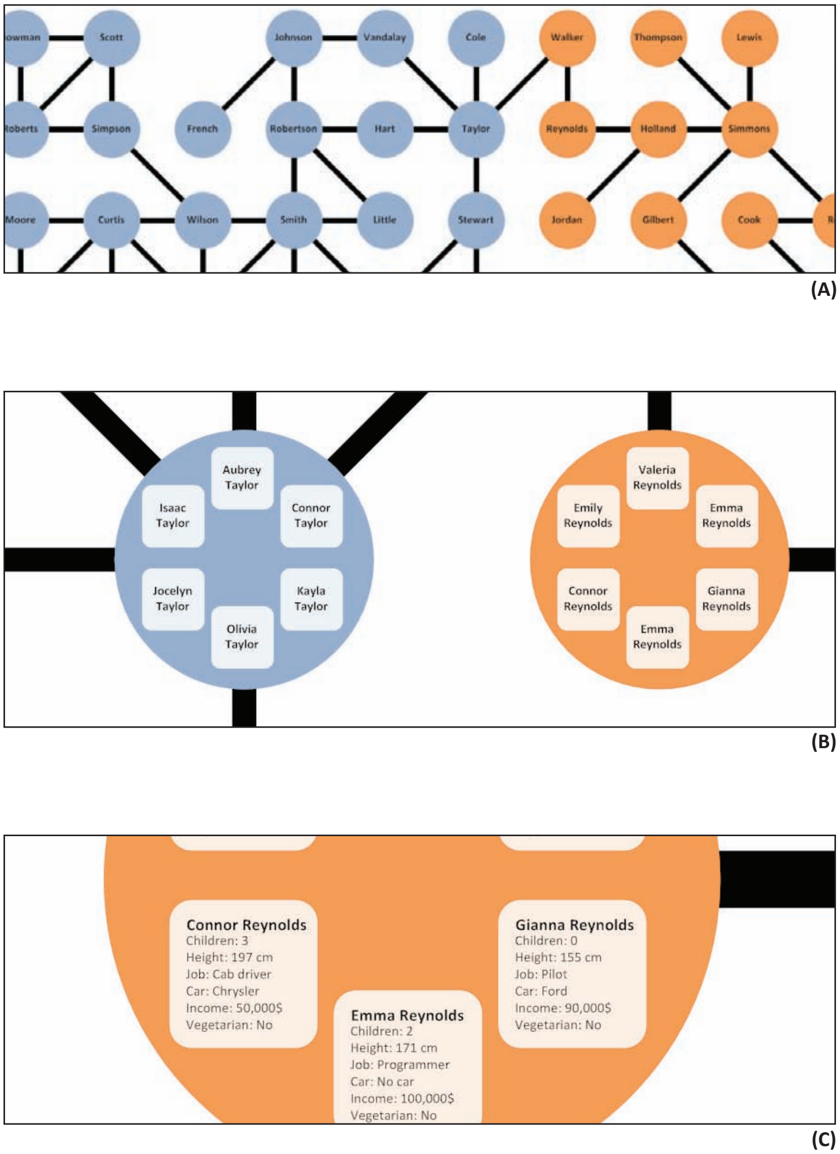

Figure 16: The social network visualization at three zoom levels. (a) Furthest away showing only family names. (b) Mid level showing family members and their full names. (c) Closest level showing family members and their attributes.

The possible solutions tried out before reaching a final working solution are described in more detail in section 6 on page 19.

10.1 Hardware implementation

Unlike the original plans to use the expensive Ubisense system the final solution proved to be relatively inexpensive. The final complete hardware implementation costs about \$2.870 as opposed to \$5.000 for the commercial user tracking hardware alone.

The final hardware implementation consists of four basic elements:

Display (\$2.130) Two ceiling mounted digital video projectors capable of a 1280x720 resolution. The video projectors implemented a technique called lens-sift that allowed to offset the projected image both vertically and horizontally to allow for easy aligning of the two projections. The final projected image measured 341x97 centimeters - this was mainly limited by the room that were available for the experiments.

User tracking (\$80) For user tracking a ultra-wide angle webcam were used. The web camera were mounted in the ceiling at a height of 310 centimeters and covered an area of 235x143 centimeters. An USB extension cord were used to connect the camera to the server at a frame rate of 30 frames per second. The recorded image was 320 by 240 pixels, thus achieving a precision of 0.49 cm vertically and 1.066 cm horizontally 30 times a second[8].

Gyro mouse (\$230) For the control case of the experiment and for selecting answers a gyroscopic mouse were used. The mouse is depicted in Figure 26 on page 54. The mouse had a range of 30 meters which was more than enough for the experiments.

Server (\$430) For running the two video projectors, the webcamera, the gyro mouse and the software a standard workstation was used. The server ran Microsoft Windows Vista on an Intel Core2 Duo 2.53 GHz CPU with 2 GB RAM and a 256 MB ATI Radeon HD 2400 XT graphics card.

Photos of the final setup can be seen in Figures 17 on page 41 through 20 on page 43

10.1.1 Perspective distortion in web camera

Because of limited height to the ceiling where the system was set up, the web camera had to employ a ultra-wide angle lens. Such a lens exhibits significant barrel distortion on the recorded image which causes otherwise straight lines to curve along the edges of the viewport. Furthermore the short distance from floor to lens causes perspective distortion on the tracked users. Figure 21 on page 43 illustrates this distortion.

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[8] The recorded area is 235 cm wide and there is 320 pixels available to record this area, this each pixel records $320/235$ centimeters

Figure 17: Photo of the tracking area and video projector setup used for the experiments.

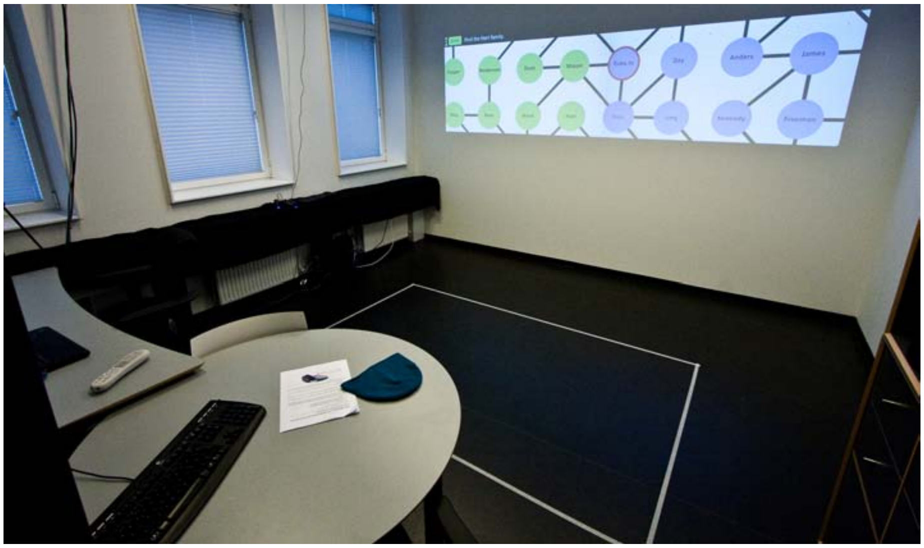

Figure 18: Photo of the tracking area and the display used for the experiments.

Figure 19: A participant in the process of solving a task.

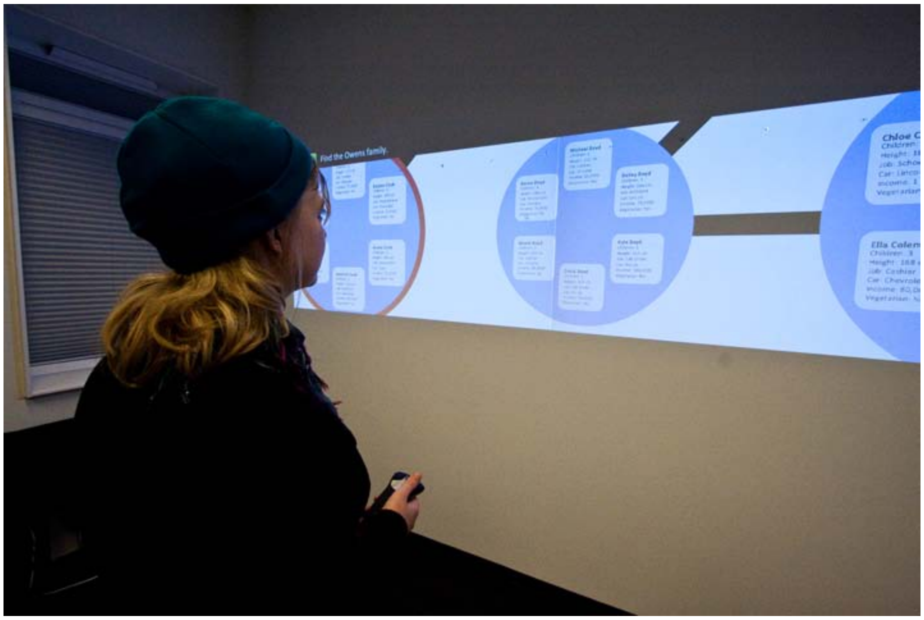

Figure 20: A participant in the process of solving a task.

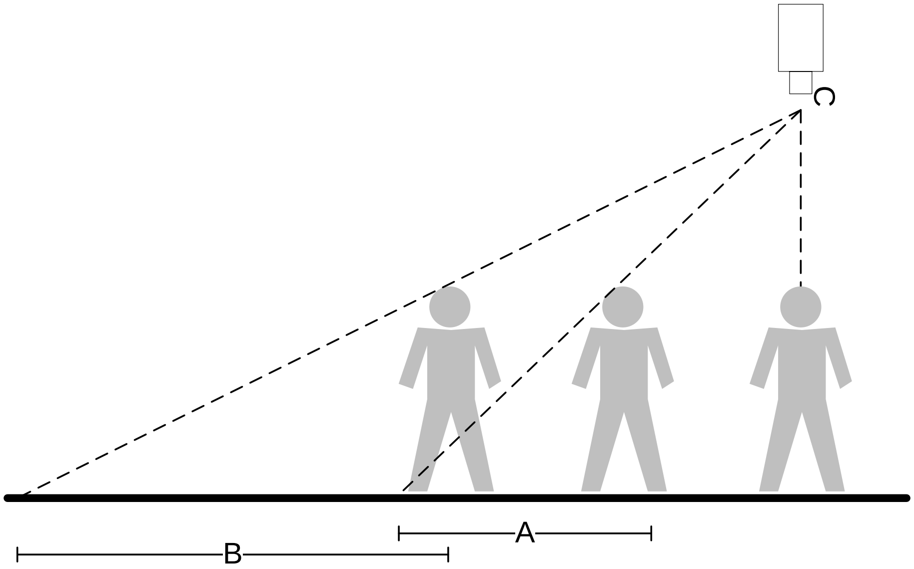

Figure 21: Illustration of the perspective distortion caused by the close proximity of the person's head to the camera. The distance B is greater than the distance A although the spacing between subjects are equal.

The further the subject is from the center of the lens the more the recorded position is offset from the actual position of the subject. This is due to it being the subjects head that is being tracked. Because of this, the taller the subject was, the more narrow the area within he could move. During the experiments all participants were therefore asked about their height as to check for correlation between this and their performance.

This also mean that some calibration was needed in order to compensate for difference between the recorded position and the users actual position. A simple technique employing interpolation between three recorded points and their known physical counterparts were used for this. The calibrated position were calculated as follows:

1. Identify the section of the display in which the position recorded by the tracking system were.
2. Find its relative position within the section to bias the computation toward one of the end points.
3. Correct the position by the biased amount of offset between defined position and measured position.

The formula used for computing the calibration of a reported position inside a calibration section were as follows[9]:

$$X_c = \frac{-B_m \cdot A_d + X \cdot A_d - X \cdot B_d + A_m \cdot B_d}{-B_m + A_m}$$

where X is the un-calibrated point, X_c is the calibrated point, B_m and B_d are the measured and defined positions of endpoint B of the calibration interval and A_m and A_d are the measured and defined positions of endpoint A of the calibration interval.

10.2 Software implementation

This section describes and elaborates on interesting aspects of the software implementation used for the system. The key components of the software are illustrated in Figure 22.

All software has been implemented using Microsoft .NET 2.0 or 3.5. For web camera access and image manipulation the AForge.NET 1.7.0[10] framework has been used. For visualization of the social network Piccolo .NET 1.2[11] has been used.

10.2.1 Object tracking

For tracking the user within the tracking area a simple color filtering technique was used. By removing all pixels not within a reasonable distance from a predefined color,

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[9] Note that the calibration is only carried out in one dimension as only the x-axis caused problems.

[10] AForge.NET is a C# framework designed for developers and researchers in the fields of Computer Vision and Artificial Intelligence - image processing, neural networks, genetic algorithms, machine learning, etc. For more info visit: `http://code.google.com/p/aforge/`

[11] Piccolo is a toolkit that supports the development of 2D structured graphics programs, in general, and Zoomable User Interfaces (ZUIs), in particular. For more info visit: `http://code.google.com/p/piccolo2d/`

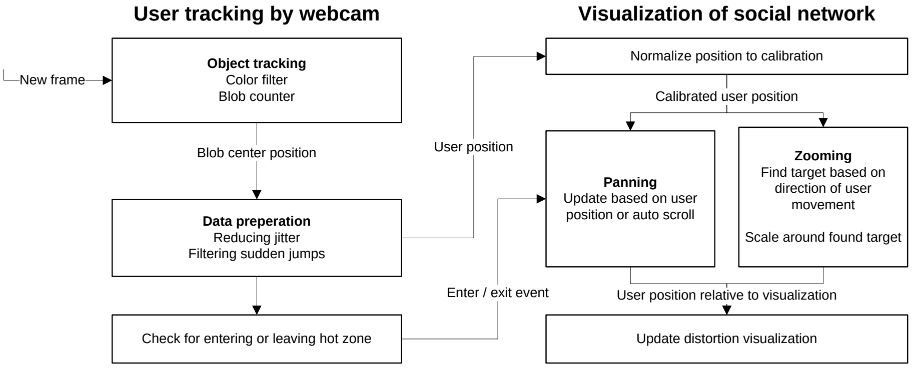

Figure 22: Illustration of processes and data flow in the software implementation.

only the object of the predefined color was left in the scene. For this to work, participants were asked to wear a dedicated hat which the system could use for color filtering. The color of the hat were chosen so it would not overlap with the color of the participants clothes. Upon start of the experiment a calibration were performed to measure the color of the hat under the current lighting conditions.

After having filtered by color the image was converted to monochrome using a threshold filter, that ensured sharp contrast between the objects edge and the rest of the scene.

Finally a blob extraction algorithm[12] was executed on the monochrome image as to find the objects bounds and thus derive its center position. Due to imperfections in the color filtering technique and varying lighting conditions the blob extraction could identify several blobs. To overcome this only the largest blob were assumed to be the tracked object. Although this is an imperfect solution it was adequate for this experiment.

10.2.2 Data preparation

Before making use of the object position found with the object tracking technique some data preparation was needed. Due to the color filtering and thresholding of the detected object the bounds of the object would increase and decrease with a couple of pixels between frames. This would cause the center position to jitter although the tracked object were stationary. To prevent this a moving average of the position, from the previous eight frames, was used. By employing this strategy the jitter would even out and be less noticeable to the user. Unfortunately this would cause some delay on the position used[13], but the advantage of reduced jitter outweighed this problem.

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[12] Blob extraction is an image segmentation technique that categorizes the pixels in an image as belonging to one of many discrete regions.

[13] When using eight frames for smoothening the user would experience a delay of $(1/F)(N/2)$ seconds, where F is the frame rate, N is the number of frames used for smoothening and $N/2$ the average value over the N fames. I.e. a 133 milliseconds delay were experienced by the user.

Furthermore, to make the visualization stay still when the user stands still, a threshold filter for user movement is implemented. This ensures that only movement further than some predefined level causes the system to react. Although this could cause the interaction to seem somewhat stuck the first couple of centimeters the user moved, pilot tests showed that this disadvantage was outweighed by the disadvantage of having the visualization jitter as one stood still. The threshold filter was only activated if the user had moved less than the threshold for 400 milliseconds.

Finally a simple heuristic approach for preventing sudden jumps in the position, caused by loosing track of the object or changing lighting conditions, were employed.

10.2.3 Zooming

When zooming a point to scale around is needed. As described in section 4 it is meaningful to estimate the users target and use this as the zooming center. For this a simple linear extrapolation technique has been implemented. The software creates a direction vector based on the users last N positions and simply calculates the intersection point of this direction vector and a line that represents the display. This intersection point is then used for the zoom center. In effect this means that the area that the user is aiming for when walking towards something, stays in the same place, thus making the interaction more natural.

10.2.4 Distortion visualization

For maintaining the distortion visualization all nodes of the network are scaled depending on their distance to the users current position. The scale of a given node is defined within the following range:

$$1 < 1 + (D/D_{Max})^C < C$$

where D is the distance from the users position to the node, D_{Max} is the width of the current view port and C is a scaling constant (1.5) found through testing. This ensures that no node is scaled up by more than 50% and that if the node is at the distance D_{Max} from the current user position (this is the case when the user is standing on one of the edges of the screen) if is 50% larger than the node right in front of the user.

11 Experiment design

To evaluate the suggested interaction design and tailored information visualization an empirical study was carried out. The study compares the performance of the novel user tracking design relative to a representative common approach using a gyroscopic mouse.

11.1 Hypotheses

Based on the ideas presented in the previous sections, especially section 4 and 7 I propose five hypotheses on the advantages and disadvantages of the suggested interaction method. Theses hypotheses will be tested in an empirical study and results will be discussed in relation to them later on. For easy reference the hypotheses are labeled H1 through H5.

H1 Users will find the developed interaction methods more engaging and fun to use. By being physical active and trying out a novel interaction technique, users will find the tasks less tedious and faster to solve, thus resulting in an overall better user satisfaction evaluation of the user tracking approaches compared to regular interaction .

H2 Users will find the developed interaction methods natural and employ natural physical movements for interaction. Users will be able to employ embodied interaction techniques and logical techniques such as walking directly towards objects instead of having to develop complex mental models for mapping between physical space and virtual space.

H3 Explorative tasks will be performed faster using the developed interaction methods. [19] showed that physical interaction techniques are less efficient for desktop-like tasks. This leads to the assumption that search as opposed to navigation tasks, are more suited for the user tracking techniques.

H4 For goal oriented tasks regular interaction will have higher efficiency than the user tracking approaches . This hypothesis works in parallel to H3. By exploiting users' experience with using a mouse and the disadvantage of using physical navigation for desktop-like tasks, users are assumed to perform easy goal oriented tasks, such as navigation, faster using regular interaction .

H5 Users will move significantly less when using regular interaction . Because users have to move when using position interaction and motion interaction , and not when using regular interaction , they are assumed to move significantly more when using the novel interaction techniques.

11.2 Design

A within-subjects randomized factorial experimental design was used. The independent variables were interaction type (gyroscopic mouse, motion tracking and position tracking) and task type (navigation, search and comparison).

To control result bias due to task sets three task sets were used. The order of task sets and interaction type were systematically varied and counter-balanced across participants using a selection of six $3X3$ Graeco-Latin Squares optimized for an equal number of interaction method and task set combinations. The Graeco-Latin squares used are listed in the Appendix, section A on page 86.

All participants performed a total of 23 tasks, 8 of these were training tasks.

Possible result bias due to data set size has not been controlled due to time constraints.

11.3 Experiment participants

A total of 18 experiment participants were recruited through my educational institution, friends and professional contacts.

Of the 18 experiment participants five were female and 13 male. The average age of the participants was 28 years ($SD = 4.6$) ranging from 24 years to 42 years. The participants rated their experience with mouse on average to 7.94 ($SD = 1.75$) and their experience with large visualizations to 3.33 ($SD = 2.50$) on a ten point scale.

11.4 Tasks

Inspired by previous studies (for instance [29] and [3]) three different task types were selected for the study:

- Navigation tasks - navigating to a single object of interest.
- Comparison tasks - navigating between and comparing attributes of two distinct objects.
- Search tasks - locating several possible answers, navigating between them and comparing attributes.

The purpose of these task types is to evaluate distinct generic task classes found in everyday life. I argue that these task classes cover a broad range of actual tasks and user behavior seen in common situations of human-computer interaction.

Each participant solved a total of 69 tasks; 23 for each interaction method whereof 8 were introduction tasks.

A task set did only concern one data set. No switching of data sets was done during task set solving. All selected data sets were constructed using an automatic data set generator created for the experiments as described in section 9.3.

Table 1 lists the number of task types for each interaction method. Introduction tasks are not included, but a corresponding distribution was used.

Task type	Count
Navigation	8
Search	3
Comparison	4
Total	15

Table 1: Number of tasks in a task set per task type.

Special emphasis has been put on navigation tasks because a clear picture of how well the interaction methods perform for simple navigation is needed. Furthermore pilot tests showed that navigation tasks are completed faster than the other task types, thus having relatively more navigation tasks evens out the time spend on each task type.

Task sets were created to ensure an equal average distance between answer locations, equal number of answers on different zoom levels as well as the same number of different distances between objects in comparison tasks.

The complete task sets used in the experiment can be found in the Appendix, Section B, on page 87.

11.4.1 Task types

Following is a description of the three task types used in the experiments. The wording of all tasks were kept as simple and identical as possible to prevent issues with understanding and reading the tasks.

Navigation tasks The most simple type of tasks used are navigation tasks. These tasks simply ask the user to locate some predefined information in the data set. This type of tasks allowed for results to be found on each of the three zoom levels - from farthest away where families could be found to closest where attributes of family members could be found. The purpose of this task type is to measure the performance of simple navigation as well as identify fundamental issues with targeting.

Examples of the wording of these tasks are presented below. No other wording of tasks, than those presented, were used. The text in the parenthesis were not shown to the user.

- Find the Powell family (answer on zoom level 1)
- Find Vanessa Brown (answer on zoom level 2)
- In the Crawford family, find the person who is a programmer (answer on zoom level 3)

Comparison tasks To evaluate the performance of navigation between two separate points in the visualization, comparison tasks were included. Users were required to navigate one or more times between the two nodes to compare them. The answer were determined by identifying which family member had the highest or lowest value of some specified attribute.

Comparison tasks only applies to the closest zoom level, but can uncover important insight into how users navigate from one position to another - i.e. is it done directly or is zooming behavior applied between the points.

Examples of the wording of these tasks are presented below. No other wording of tasks, than those presented, were used.

- Among the Lee and Wyatt families, find the person who is the tallest.
- Among the Dixon and Rose families, find the person who earns the most.

Search tasks Search tasks with two classes of distance between answer candidates were used - regular search tasks and route following search tasks. The regular search tasks asked the user to locate a family member based on some search criteria such as the first letter of the family name, type of car driven, number of children, etc. Path following tasks asked participants to search for the highest value between the families directly connected to some predefined point of origin. By this distinction regular search task dealt with a large set of nodes with the answer candidates scattered evenly and the path following search tasks dealt with answer candidates in close proximity to some point of origin.

Examples of the wording of these tasks are presented below. No other wording of tasks, than those presented, were used.

- Among the families directly connected to the Wirick family, find the school teacher who earns the most.
- Among the families starting with R in the orange segment, find the pilot who earns the most.

The purpose of search tasks is to evaluate performance under cognitive challenging conditions - i.e. users had to remember a complex task, search for possible candidates and remember the current best value.

11.5 Procedure

After arriving participants was given a short oral welcome. They were hereafter instructed to read a four page written introduction explaining the agenda for the experiment, details about the answering and reading of tasks, the network visualization and details about the three interaction methods. The written introduction, in Danish, can be found in the Appendix starting page D.

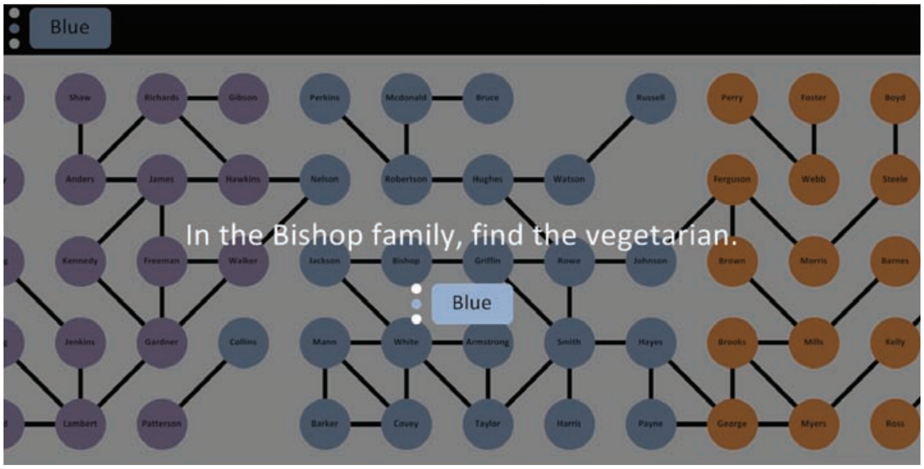
Before letting participants try out the interaction methods a calibration procedure had to be completed. This procedure consisted of having the participants walk a full circle in the motion area as well as stand in front of three predefined points on the display.

For each interaction method a set of eight introduction tasks were given to make the participants acquainted with the interaction method. The participants were encouraged to ask questions, to play around with the interface and the interaction method and to take as long as they needed to answer the introduction tasks during the introduction.

Before participants started solving the three task sets, they were asked to complete the tasks as fast as possible, without errors or asking questions during the experiment. Also they were ensured that it was the interaction methods and not them that were being tested.

All questions were presented to the participant in center of the screen. The question text were written in white on a semi transparent black background as seen in Figure 23 on page 51. Participants were instructed to tell the experiment leader when they have read and understood questions, after which the experiment leader would remove the question from the middle of the screen. This was done as to exclude time used for reading and understanding questions from the final results. During the solving of a task the current question was available for reference in the top left of the display, as seen in Figure 24 on page 51.

Along with questions an graphical indication of where the answer could be found were included. The indication, as shown in Figure 25, told the participant in what segment of the data set and in what part of a segment that the answer could be found. This approach was chosen to minimize the complexity of the written tasks as well as



In the Bishop family, find the vegetarian.

Figure 23: An example of a task displayed to the user before solving the task had been initiated. The contrast between the task text and the visualization in the background was stronger in the experiment than shown here due to lighting conditions.

In the Bishop family, find the vegetarian.

Children: 1
Height: 193 cm
Job: School teacher
Car: No car
Income: 20,000$
Vegetarian: Yes

Ashley Bishop
Children: 2
Height: 150 cm
Job: Programmer
Car: Chrysler
Income: 80,000$
Vegetarian: No

Nicole Bishop
Children: 0
Height: 195 cm
Job: Architect
Car: Ford
Income: 40,000$
Vegetarian: No

Ella Bishop
Children: 2
Height: 181 cm
Job: Architect
Car: No car
Income: 50,000$
Vegetarian: No

Bailey Bishop
Children: 2
Height: 169 cm
Job: Pilot
Car: No car
Income: 100,000$
Vegetarian: No

Ryan Bishop
Children: 0
Height: 169 cm
Job: School teacher
Car: No car
Income: 40,000$
Vegetarian: No

Figure 24: The current task, as well as the graphical indication of where the answer could be found, was always visible in the top of the display during solving of tasks.

minimized the need for time consuming scanning of the network. Pilot experiments showed that the chosen information visualization for the social networks were causing participants to scan nodes sequentially for a right answer. By indicating where the answer could be found the number of items to scan, and thus the time needed, were reduced. Furthermore pilot testing showed that writing this indication of answer positions in text caused tasks to seem complex and harder to remember, thus creating a unnecessary need for referencing the question text in the top of the display. Using the indication of answer location and a graphical approach greatly reduced the overall complexity of tasks.

Figure 25: An example of the graphical indication of where a answer could be located.

11.6 User satisfaction

To evaluate users subjective experience of the interaction methods four questionnaires for user satisfaction were used. Each task set solved using a given interaction method was followed by a questionnaire concerning that interaction method. The questionnaire was constructed from selected questions from QUIS [9] plus similar questions directly related to the evaluated interaction methods and tasks. Questions were rated on a ten point phrase completion scale. The questionnaires included the questions listed in table 2 as well as room for stating which user interface the participant had just used.

After having completed all three parts of the experiment participants were handed a final questionnaire asking for their gender, age, height[14], a ranking of the three interaction methods and the questions in table 3. The questions in the final questionnaire were also rated using ten point phrase completion scales.

Finally a brief interview was carried out giving the participants the opportunities to verbally express their experience as well as advantages and disadvantages for each of the interaction methods. This interview was documented using notes written down by the experiment leader. The full questionnaires can be found in appendix C on page 90.

11.7 Dependent variables

Measurements of usability were documented by response time per task. Only the time from after the participant stated that a question had been read and understood until an answer had been selected, were measured.

The participants answers were recorded for later analysis; this was used to derive error measurements.

To analyze interaction patterns all interaction with the user interface were logged. This includes the users' position and the position of the viewport on the full canvas as

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[14] The reasons for including height in the data collection is elaborated in section 10.1.1

How did you find the interface in general?	
Very poor	Very good
How was the interface to use?	
Terrible	Wonderful
Hard	Easy
Frustrating	Pleasant
Rigid	Flexible
Boring	Fun
Confusing	Clear
Insert	Sensitive
Inadequate power	Adequate power
The interaction method was physically tiring to use.	
I agree	I disagree
The user interface was hard to learn.	
I agree	I disagree
There weren't enough time to learn the interaction method.	
I agree	I disagree
How did you perceive the tasks?	
Very challenging	Very easy
The social network was...	
Hard to understand	Easy to understand
Hard to overview	Easy to overview
Methods you were trying to locate were...	
Hard to locate	Easy to locate
Persons and families you were trying to locate was...	
Hard to locate	Easy to locate

Table 2: Questionnaire for user satisfaction. Questions were rated on a ten-point phrase completion scale.

How much experience do you have with using a mouse?	
Very little	Very much
How much experience do you have viewing large visualizations	
Very little	Very much

Table 3: Final questionnaire for user satisfaction. Questions were rated on a ten-point phrase completion scale.

well as all interactions with the mouse (clicking of buttons, answering of questions, etc.).

Finally general observations about the users interaction were documented manually on a semi structured form including the time of the observation, description of the observed as well as initial thoughts about reasons for the observed behavior.

11.8 Equipment and location

All experiments were carried out using the same equipment on the same location and under similar lighting conditions.

For executing the experiment application a desktop computer was connected to two ceiling mounted video projectors aligned to make up a display size of 341x97 centimeters at a resolution of 2560x720 pixels.

Due to the technical implementation (described in section 10) participants were asked to wear a woolly hat during all parts of the experiment.

For use in the control case and for selecting answers, enable movement detection in the movement based interaction method and for scrolling vertically in the two novel interaction methods a gyroscopic in-air mouse, model Go Pro Mouse from Gyration, was used. The mouse allowed for full in-air control of the mouse cursor on the display. For enabling motion detection in the mouse itself, a button on it's bottom had to be pressed. This button is located just at the index finger and allowed hassle-free control over when movement were detected (see Figure 26).

Figure 26: The gyration mouse used throughout the experiments.

12 Results

The following section presents the results of the empirical study described in section 11. Results are reported in terms of efficiency, accuracy and user satisfaction. Furthermore an analysis of the interaction behavior presented by participants is proposed.

12.1 Efficiency

Table 4 on page 55 lists the efficiency results from the user study. The results include tasks that are both correctly and incorrectly answered. Preliminary analysis of results with and without incorrect answers showed little difference. Additionally analysis showed that only a few of the incorrect answers were extreme outliers, so filtering for this attribute would yield little difference. All testing of significant differences on completion times have been carried out after logarithmic transformation to ensure a normal distribution. Regular means and standard deviations are reported before logarithmic transformation. Training exercises have been excluded from the results. Finally, no significant correlation is seen between participants' height and completion times (Pearson product-moment correlation coefficient, $r = -.37$ for position interaction and $r = 0.22$ for motion interaction), as discussed in section 10.1.1, so no correction for this has been performed.

		Interaction type					
		Regular		Position		Motion	
		M	SD	M	SD	M	SD
Task type	Navigate	17.0	8.8	18.0	8.5	19.9	10.4
	Compare	35.1	14.6	33.6	11.5	38.1	19.2
	Search	69.7	31.2	67.0	25.1	61.8	19.9
	Average	32.4	26.4	32.0	23.5	33.1	22.3

Table 4: Mean and standard deviation of completion times (in seconds) per task type and interaction type.

Few differences between interaction types were observed. Position interaction was 1.3% faster than regular interaction and 3.7% faster than motion interaction on average, but the results are statistically insignificant ($p = .971$ and $p = .512$). regular interaction is 2.3% slower than motion interaction , but again without statistical significance ($p = .493$). All the pairwise comparisons are summarized in table 5 on page 56.

Within-subjects repeated measures analysis of variance also show no significant main effect of the tree interaction types, $F(2,34) = .303$, $p = .741$. However interaction of the two factors is significant, $F(4,68) = 2.704$, $p = .037$ as is the main effect task type at $F(2,34) = 509.272$, $p < .000$. Box plots of the results are shown in Figure 27 on page 56.

For all interaction types significant differences are observed between task type ($p \leq .001$), as easily seen in Figure 28 on page 57.

12.1.1 Analysis per task type

In the following efficiency results are analyzed per task type. Mean and standard deviation of completion times for navigation, compare and search tasks are shown in table 7 on page 59, 8 on page 60 and 9 on page 61. Box plots for completion time per inter-

(I) interaction	(J) interaction	Mean Difference (I-J)	Std. Error	Sig.[a]	95% CI for Difference[a] Lower Bound	95% CI for Difference[a] Upper Bound
Regular	Position	-0.002	.051	.971	-0.110	0.106
	Motion	-0.034	.049	.493	-0.138	0.069
Position	Regular	0.002	.051	.971	-0.106	0.110
	Motion	-0.032	.048	.512	-0.135	0.070
Motion	Regular	0.034	.049	.493	-0.069	0.138
	Position	0.032	.048	.512	-0.070	0.135

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 5: Pairwise comparisons of average completion times for all interaction types.

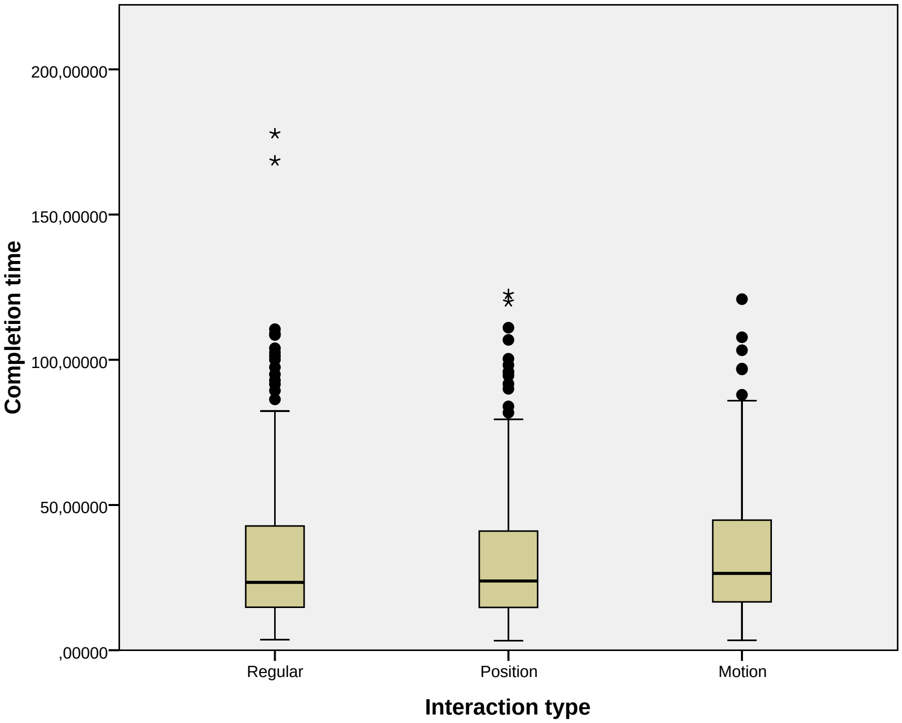

Figure 27: Box plot of completion time per interaction type.

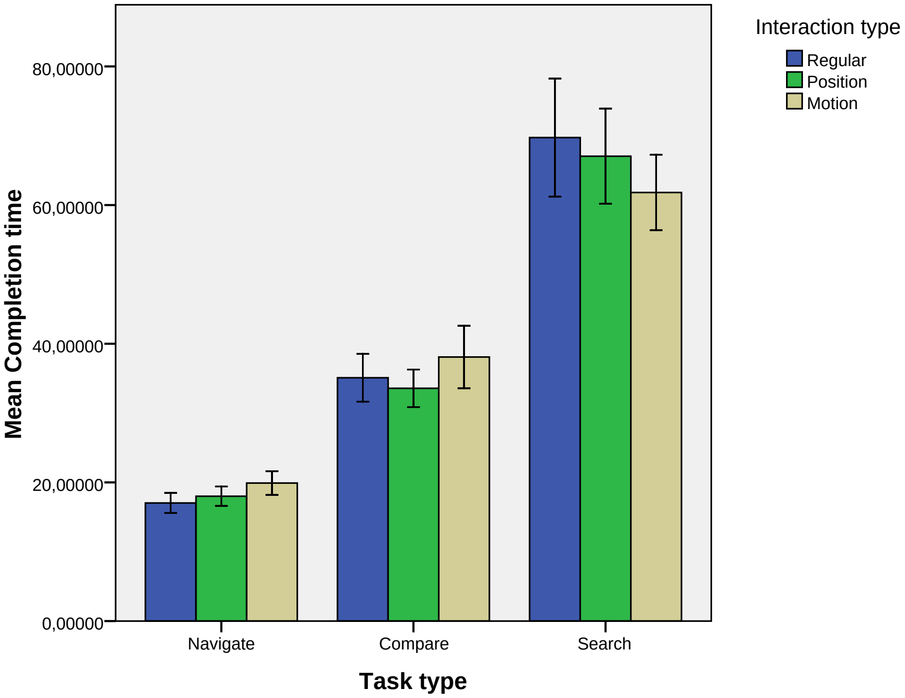

Figure 28: Mean task completion time per task type and interaction type. Error bars: 95% confidence interval.

action type are shown in Figures 29 on page 59 to 31 on page 62. Pairwise significance tests between interaction types per task type are summarized in table 6 on page 58.

			[a]		95% CI for Difference [a]	
task	(I)	(J)	Mean Diff. (I-J)	Sig.[a]	Lower Bound	Upper Bound
Navigate	Regular	Position	-0.069	.304	-0.206	0.068
		Motion	-0.141	.051	-0.282	0.001
	Position	Regular	0.069	.304	-0.068	0.206
		Motion	-0.072	.373	-0.237	0.094
	Motion	Regular	0.141	.051	0.000	0.282
		Position	0.072	.373	-0.094	0.237
Compare	Regular	Position	0.030	.649	-0.107	0.167
		Motion	-0.058	.292	-0.171	0.054
	Position	Regular	-0.030	.649	-0.167	0.107
		Motion	-0.088	.154	-0.212	0.036
	Motion	Regular	0.058	.292	-0.054	0.171
		Position	0.088	.154	-0.036	0.212
Search	Regular	Position	0.033	.679	-0.133	0.200
		Motion	0.096	.170	-0.045	0.237
	Position	Regular	-0.033	.679	-0.200	0.133
		Motion	0.062	.352	-0.075	0.200
	Motion	Regular	-0.096	.170	-0.237	0.045
		Position	-0.062	.352	-0.200	0.075

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 6: T-test of completion times per interaction type for compare tasks.

Results for navigation tasks show little difference with high variance between interaction types. On average navigation tasks were performed in 17.03 seconds for regular interaction ($SD = 8.80$), 18.00 seconds for position interaction ($SD = 8.5$) and 19.91 seconds for motion interaction ($SD = 10.41$). The 16.9% difference between regular interaction and motion interaction show little statistical significance with $p = .051$.

As for comparison tasks, observed differences in task completion times are insignificant. Results for regular interaction ($M = 35.09$ and $SD = 14.64$) and position interaction ($M = 33.57$ and $SD = 11.52$) differ by only 4.5% with $p = .649$. The most significant difference is seen between position interaction and motion interaction with position interaction being 13.4% faster than motion interaction ($M = 38.09$ and $SD = 19.19$), but the results are inconclusive with $p = .154$. Finally motion interaction is seen to be 8.5% faster than regular interaction for comparison tasks, but the results are insignificant ($p = .292$).

No statistically significant results for difference between task completion times for

		Completion time	
		M	SD
Interaction type	Regular	17.03	8.80
	Position	18.00	8.50
	Motion	19.91	10.41
	Average	18.31	9.33

Table 7: Mean and standard deviation of completion times per interaction type for navigation tasks.

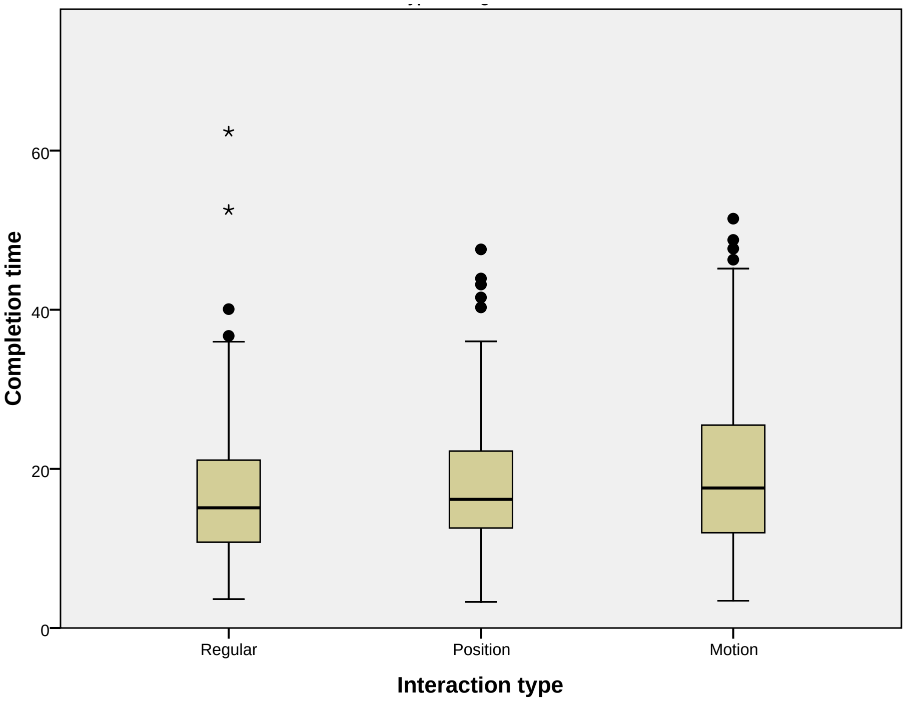

Figure 29: Box plot of completion times per interaction type for navigation tasks.

		Completion time	
		M	SD
Interaction type	Regular	35.09	14.64
	Position	33.57	11.52
	Motion	38.09	19.19
	Average	35.58	15.48

Table 8: Mean and standard deviation of completion times per interaction type for compare tasks.

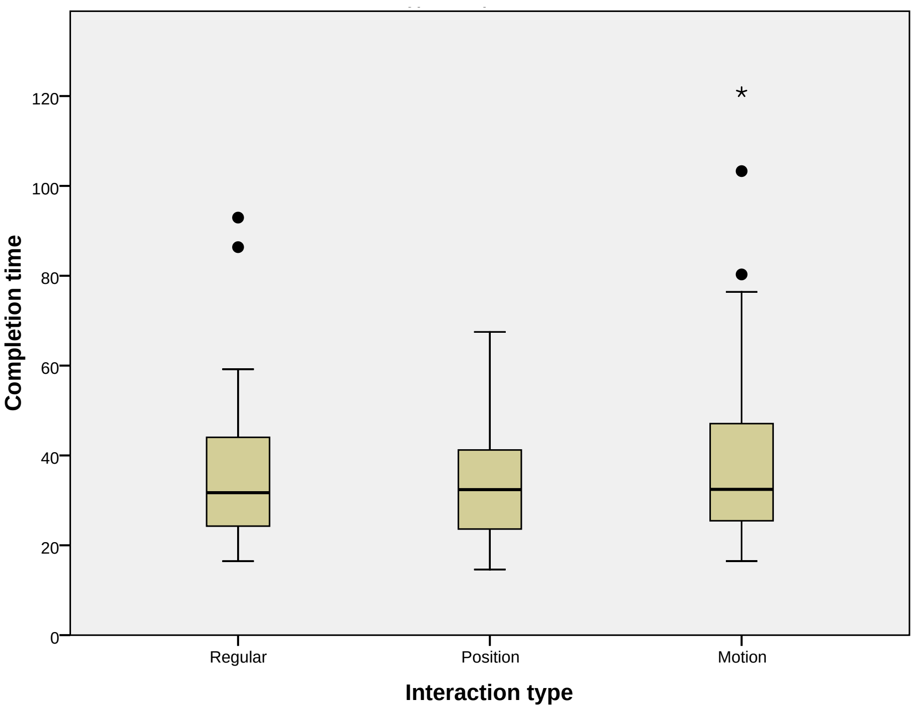

Figure 30: Box plot of completion times per interaction type for comparison tasks.

search tasks are found. Mean completion times for regular interaction ($M = 69.74$ and $SD = 31.17$) are found to be slower than for both position interaction ($M = 67.05$ and $SD = 25.13$) and motion interaction ($M = 61.81$ and $SD = 19.95$), but the results are statistically insignificant with $p = .605$ for the regular interaction - position interaction pair and $p = .113$ for the regular interaction - motion interaction pair. Finally the observed 8.5% performance increase from position interaction to motion interaction are insignificant at $p = .352$.

		Completion time	
		M	SD
Interaction type	Regular	69.74	31.17
	Position	67.05	25.13
	Motion	61.81	19.95
	Average	66.20	25.88

Table 9: Mean and standard deviation of completion times per type for search tasks.

12.2 Accuracy

Accuracy are measured by comparing participants answers to a defined correct answer. For navigation tasks, where families had to be located, selection of a family member is also deemed a correct answer.

Repeated measures ANOVA showed no statistically significant difference between interaction type, $F(2,34) = 1.962$, $p = .156$, or interaction between interaction type and task type, $F(4,68) = 1.050$, $p = .388$. Per task type the accuracy are significantly different with $F(2,34) = 6.387$, $p = .004$.

In total regular interaction showed an accuracy of 98% ($SD = .08$), position interaction showed an accuracy of 97% ($SD = .09$) and motion interaction showed an accuracy of 93% ($SD = .16$). Results by interaction type and task type are shown in table 10 on page 61.

		Interaction type					
		Regular		Position		Motion	
		M	SD	M	SD	M	SD
Task type	Navigate	1,00	,00	,99	,03	1,00	,00
	Compare	,99	,06	,97	,08	,94	,11
	Search	,94	,13	,94	,13	,85	,23
	Total	,98	,08	,97	,09	,93	,16

Table 10: T-test of completion times per interaction type for search tasks.

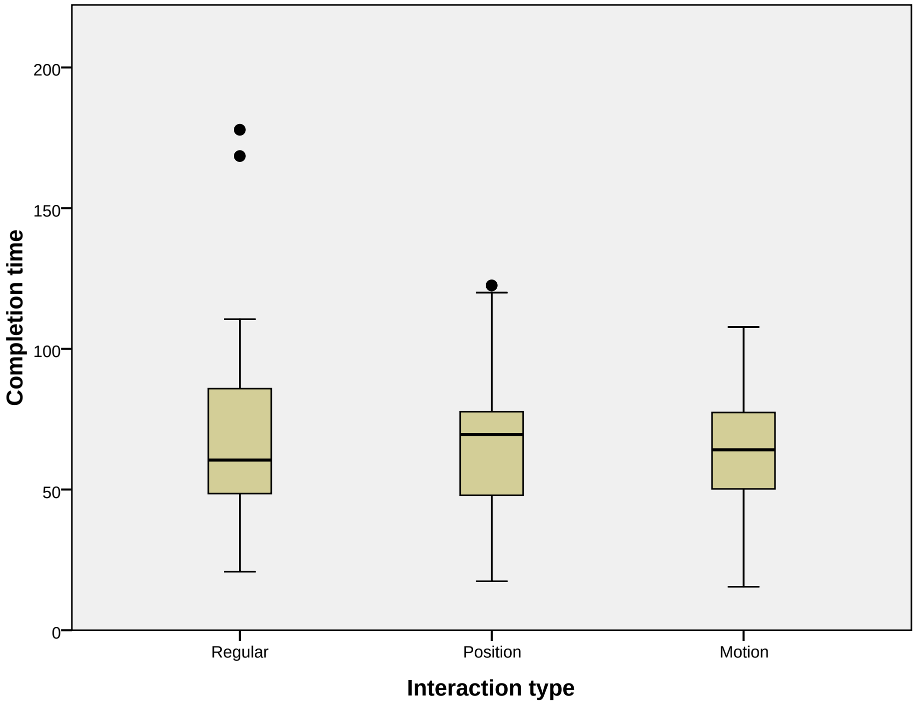

Figure 31: Box plot of completion times per interaction type for search tasks.

Pairwise t-test for interaction types per task type showed no significant differences. The results are summarized in table 11 on page 63.

		Paired Differences					
				95% Confidence Interval			
		M[b]	SD	Lower	Upper	t	p
Navigate [a]	Regular - Position	0,02	0,09	-0,02	0,06	1,000	,331
	Position - Motion	-0,02	0,09	-0,06	0,02	-1,000	,331
Compare	Regular - Position	0,03	0,22	-0,08	0,14	,566	,579
	Regular - Motion	0,09	0,27	-0,05	0,22	1,374	,187
	Position - Motion	0,06	0,31	-0,09	0,21	,809	,430
Search	Regular - Position	0,00	0,37	-0,18	0,18	,000	1,000
	Regular - Motion	0,14	0,32	-0,02	0,30	1,845	,083
	Position - Motion	0,14	0,44	-0,08	0,36	1,338	,198

a.T cannot be computed for Regular - Motion because the standard error of the difference is 0

b.Values are computed on arcsine transformed results to ensure a normal distribution.

Table 11: T-test of difference in correctness per interaction type and task type.

12.3 Satisfaction

User satisfaction was measured using the questionnaires described in section 11.6.

On average regular interaction was ranked highest[15] of the three interaction types with $M = 1.83$ ($SD = .79$). The interaction types position interaction and motion interaction were ranked similar with $M = 2.11$ ($SD = .83$) and $M = 2.06$ ($SD = .87$). A non parametric Kruskal-Wallis one-way analysis of variance showed no significant difference between the rankings, $z = .564$. This result is supported by multivariate analysis of variance on the questionnaires which shows no significant difference between the average score for each interaction type ($F(32,72) = 1.291$, $p = 0.182$).

On average the scores on a ten point phrase completion scale rated 6.36 ($SD = 2.19$) for regular interaction , 5.82 ($SD = 2.30$) for position interaction and 5.53 ($SD = 2.53$) for motion interaction . The observed differences are not statistically significant as showed in Table 12 on page 64.

Table 13 summarizes mean and standard deviation for all the questions in the questionnaire.

Table 14 on page 65 reports results of pairwise t-test between the three interaction types on each question.

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[15] A rank on 1 indicates the interaction type was ranked as the best by the participants and a rank of 3 indicates that the interaction type was ranked as the worst.

	Paired Differences					
	95% Confidence Interval					
	M	SD	Lower	Upper	t	p
Motion - Position	-0,29	1,70	-1,13	0,56	-,719	,482
Motion - Regular	-0,83	2,00	-1,83	0,17	-1,757	,097
Position - Regular	-0,54	1,62	-1,35	0,26	-1,421	,173

Table 12: T-test of difference in satisfaction per interaction type.

	Interaction type					
	Motion		Position		Regular	
	M	SD	M	SD	M	SD
Boring - Fun	6.7	2.6	6.4	2.0	6.2	2.3
Confusing - Clear	4.8	2.5	6.1	2.6	5.9	2.0
Enough time to learn - Too little time to learn	6.8	2.5	7.6	1.6	7.7	1.5
Frustrating - Pleasant	3.7	2.4	4.5	2.4	5.3	2.4
Hard - Easy	3.9	2.4	5.2	2.5	5.1	2.3
Hard to lear - Easy to learn	5.5	2.6	6.5	2.1	6.1	2.5
Hard to locate - Easy to locate	6.7	2.2	6.3	1.8	7.6	1.4
Hard to overview - Easy to overview	6.3	2.4	5.7	2.3	7.8	1.2
Hard to understand - Easy to understand	7.6	1.7	7.4	1.7	8.1	1.1
Inadequate power - Adequate power	5.1	2.4	5.7	1.9	6.9	1.3
Inert - Sensitive	5.7	2.2	5.9	2.7	6.3	1.7
Rigid - Flexible	5.0	2.5	5.2	2.1	5.8	2.4
Terrible - Wonderful	4.9	2.3	5.1	2.3	5.6	2.2
Tiring - Not tiring	4.9	2.7	4.3	2.5	5.5	3.1
Very challenging tasks - Very easy tasks	5.6	2.0	5.6	1.8	5.9	1.9
Very poor - Very good	5.2	2.3	5.5	2.1	5.9	2.1

Table 13: Mean and standard deviation for questions in questionnaire on a ten point phrase completion scale.

		Paired Differences					
				95% CI			
Question		M	SD	Lower	Upper	t	p
Boring - Fun	Regular - Position	-0.17	2.77	-1.54	1.21	-.255	.802
	Regular - Motion	-0.50	3.31	-2.15	1.15	-.640	.530
	Position - Motion	-0.33	2.06	-1.36	0.69	-.687	.501
Confusing - Clear	Regular - Position	-0.11	2.19	-1.20	0.98	-.215	.832
	Regular - Motion	1.17	2.94	-0.29	2.63	1.686	.110
	Position - Motion	1.28	3.43	-0.43	2.98	1.582	.132
Enough time to learn - Too little time to learn	Regular - Position	0.06	1.89	-0.89	1.00	.124	.902
	Regular - Motion	0.83	2.53	-0.42	2.09	1.399	.180
	Position - Motion	0.78	1.80	-0.12	1.67	1.833	.084
Frustrating - Pleasant	Regular - Position	0.83	2.98	-0.65	2.31	1.188	.251
	Regular - Motion	1.67	3.48	-0.06	3.40	2.031	.058
	Position - Motion	0.83	3.20	-0.76	2.43	1.104	.285
Hard - Easy	Regular - Position	-0.11	3.07	-1.64	1.41	-.154	.880
	Regular - Motion	1.17	3.29	-0.47	2.80	1.502	.151
	Position - Motion	1.28	3.74	-0.58	3.14	1.450	.165
Hard to lear - Easy to learn	Regular - Position	-0.39	3.13	-1.94	1.17	-.528	.605
	Regular - Motion	0.61	3.13	-0.94	2.17	.829	.419
	Position - Motion	1.00	2.89	-0.44	2.44	1.468	.160
Hard to locate - Easy to locate	Regular - Position	1.22	2.07	0.19	2.25	2.500	**.023**
	Regular - Motion	0.89	2.37	-0.29	2.07	1.589	.131
	Position - Motion	-0.33	1.97	-1.31	0.65	-.718	.483
Hard to overview - Easy to overview	Regular - Position	2.17	2.18	1.08	3.25	4.224	**.001**
	Regular - Motion	1.50	2.28	0.37	2.63	2.789	**.013**
	Position - Motion	-0.67	3.41	-2.36	1.03	-.829	.419
Hard to understand - Easy to understand	Regular - Position	0.67	1.19	0.08	1.26	2.380	**.029**
	Regular - Motion	0.56	1.72	-0.30	1.41	1.368	.189
	Position - Motion	-0.11	1.57	-0.89	0.67	-.301	.767
Inadequate power - Adequate power	Regular - Position	1.17	1.65	0.34	1.99	2.993	**.008**
	Regular - Motion	1.78	2.49	0.54	3.01	3.033	**.008**
	Position - Motion	0.61	2.70	-0.73	1.96	.959	.351
Inert - Sensitive	Regular - Position	0.39	3.13	-1.17	1.94	.528	.605
	Regular - Motion	0.61	2.77	-0.77	1.99	.937	.362
	Position - Motion	0.22	2.82	-1.18	1.62	.334	.742
Rigid - Flexible	Regular - Position	0.56	3.26	-1.06	2.18	.723	.479
	Regular - Motion	0.78	3.26	-0.85	2.40	1.011	.326
	Position - Motion	0.22	2.29	-0.92	1.36	.412	.686
Terrible - Wonderful	Regular - Position	0.44	3.01	-1.05	1.94	.626	.540
	Regular - Motion	0.61	3.26	-1.01	2.23	.796	.437
	Position - Motion	0.17	2.09	-0.87	1.21	.338	.740
Tiring - Not tiring	Regular - Position	1.17	3.40	-0.52	2.86	1.456	.164
	Regular - Motion	0.56	3.84	-1.35	2.46	.614	.547
	Position - Motion	-0.61	2.25	-1.73	0.51	-1.151	.266
Very challenging tasks - Very easy tasks	Regular - Position	0.33	2.00	-0.66	1.33	.707	.489
	Regular - Motion	0.33	2.20	-0.76	1.43	.644	.528
	Position - Motion	0.00	1.91	-0.95	0.95	.000	1.000
Very poor - Very good	Regular - Position	0.44	2.50	-0.80	1.69	.754	.461
	Regular - Motion	0.72	3.16	-0.85	2.29	.970	.346
	Position - Motion	0.28	1.99	-0.71	1.27	.591	.562

As can be seen only six differences are significant[16]. These are listed in table 15 on page 66. The reported difference is how much more the first listed interaction type is rated compared to the second listed.

Question	Interaction pair		Difference	p
Hard to locate - Easy to locate	Regular	Position	12.1%	.023
Hard to overview - Easy to overview	Regular	Position	36.8%	.001
	Regular	Motion	23.8%	.013
Hard to understand - Easy to understand	Regular	Position	9.5%	.029
Inadequate power - Adequate power	Regular	Position	21.0%	.008
	Regular	Motion	35.3%	.008

Table 15: Summary of significant differences in user satisfaction.

12.3.1 Advantages and disadvantages

At the end of each experiment a short informal interview with the participant was held. This section outlines some of the recurring themes of these interviews.

- Of the 18 participants eight expressed that it was frustrating when the hot zones were activated unintentionally while using position interaction
- Six participants reported problems with unintentional jumps of the visualization, caused by problems for the system to keep track of their position.
- Five participants expressed that, using position interaction or motion interaction , movement of the visualization while looking at it could cause temporary physical discomfort such as nausea.
- Five participants reported that it was easier to maintain concentration while using position interaction and motion interaction because they were moving and staying active.
- Five participants reported that using the mouse for prolonged periods of time could place strain on shoulders.
- Five participants reported difficulties differentiating between the purple and blue color.
- Four participants noted that it was inconvenient that the head was being tracked as it required them to strand relatively still and not move their head freely.
- Four participants expressed that it was hard to have to deal with the many buttons required to operate motion interaction .

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[16] If Bonferroni correction is carried out in the results only differences for the questions ”Hard to overview - Easy to overview” for the ”Regular - Position” pair and ”Inadequate power - Adequate power” for the ”Regular - Motion” pair are significant. However it have been chosen to analyze the results without this correction as they show some interesting points.

- Four participants expressed that regular interaction was tedious and felt like a chore.
- Four participants reported they felt more in control of what happened when using motion interaction because they had the possibility to stop horizontal movement.
- Five participants reported that looking on the display for prolonged periods of time was tiring for the eyes.
- Three participants reported that motion interaction was too sensitive when the user were close to the display.

12.4 Interaction analysis

During the experiments users positions were logged as to analyze their behavior and quantify how and how much they moved.

Figures 32 on page 68 to 34 on page 68 shows the center of the viewport relative to the visualization canvas as a whole. Blue dots represent where questions have been read and green dots represent where answers have been selected. In all three figures the five rows of family nodes are easily seen outlined by the dots.

In contrast to regular interaction both position interaction and motion interaction show distinct horizontal lines along especially the three middle levels. Furthermore, transitions between levels are straight lines as opposed to the curves of Figure 32 on page 68. This is clear evidence of the interaction behavior exhibited by participants when using the two user tracking interactions. Most users were observed to employ a stepwise interaction technique for finding targets with the following steps

1. Walk back to the edge of the tracked area to get an overview of the visualization.
2. Walk sideways to let the target be directly in front of the user.
3. Walk directly towards the target.
4. Adjust the vertical position of the view port when the target were about to leave the view port due to zooming.
5. Repeat the two steps above until the target were reached.

This results in the jagged transitions between levels as seen in Figure 33 on page 68 and 34 on page 68. For motion interaction the transition lines are seen to be less jagged than for position interaction - this is properly due to the user having more control over when the system would react on sideways movement of the user.

Figures 35 on page 69 and 36 on page 70 shows the tracked path of the users on the tracked area. Unfortunately, due to a bug in the logging software, no data valid exist for regular interaction . Observations and notes indicate that only three users actually moved - other than changing posture - when using regular interaction . On average users moved 1.208 units with position interaction and 1.274 for motion interaction . results per task type are showed in table 16 on page 69. Multivariate analysis of variance showed no significant difference between interaction type ($p = .414$) and interaction

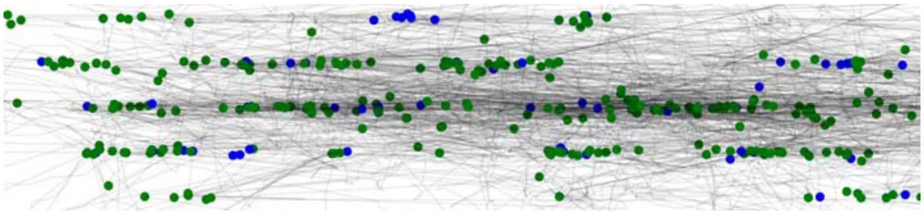

Figure 32: Center of the view port on the canvas for all participants using regular interaction .

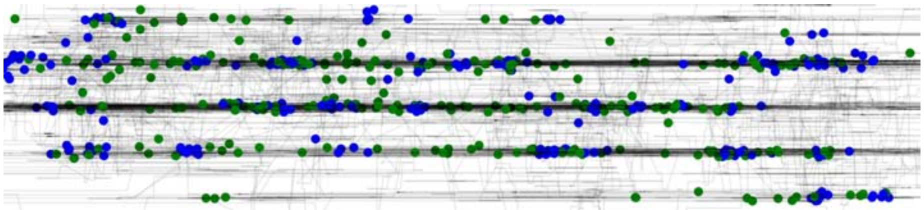

Figure 33: Center of the view port on the canvas for all participants using position interaction .

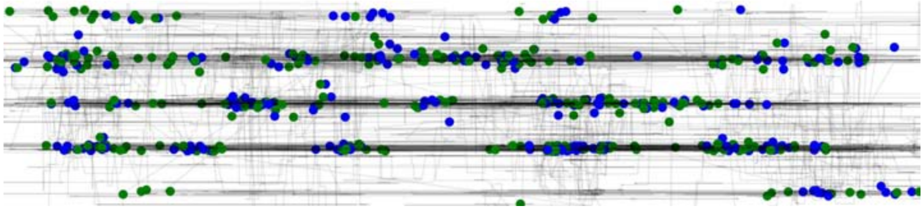

Figure 34: Center of the view port on the canvas for all participants using motion interaction .

between interaction type and task type ($p = .496$). Difference between task types are significant at $p \leq .001$. Pearson product-moment correlation coefficient shows a strong correlation between distance moved and completion times at $r = .878$ and $p \leq .001$.

	Position		Motion	
	M	SD	M	SD
Compare	1234	555	1431	1016
Navigate	752	449	777	462
Search	2388	1335	2387	1222
Average	1208	964	1274	1033

Table 16: Mean and standard deviation of distance moved per task type and interaction type.

The figures clearly show step one of the above mentioned interaction strategy by having all green dots (indication of read questions) along the back edge of the tracked area. Furthermore the Figures show a clear, and well known, indication that most questions needed to be answered at the closest zoom level.

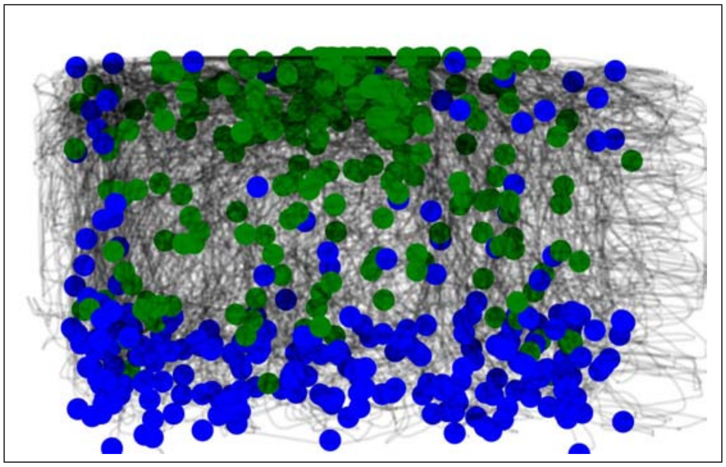

Figure 35: Tracked path of all participants using position interaction .

Additionally the users location when selecting answers are more densely compacted toward the middle of the tracked area for position interaction than motion interaction . This is caused by the scrolling hot zones which users would avoid when selecting answers.

As noted previously having the participants heads being the tracked objects had some problematic implications for the interaction. Because people by nature sway a little when walking - caused by lifting the foot and offsetting the center of gravity -

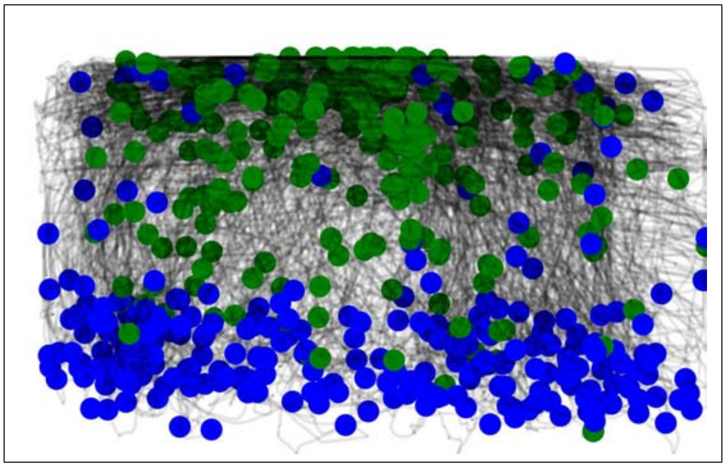

Figure 36: Tracked path of all participants using motion interaction .

their tracked position would display a wave like path rather than a straight line. The amplitude of the wave would increase with the users height as described in section 10.1.1. A good example of such a wave like path are showed in Figure 37 on page 70. Darker path color indicates a faster speed by the participant.

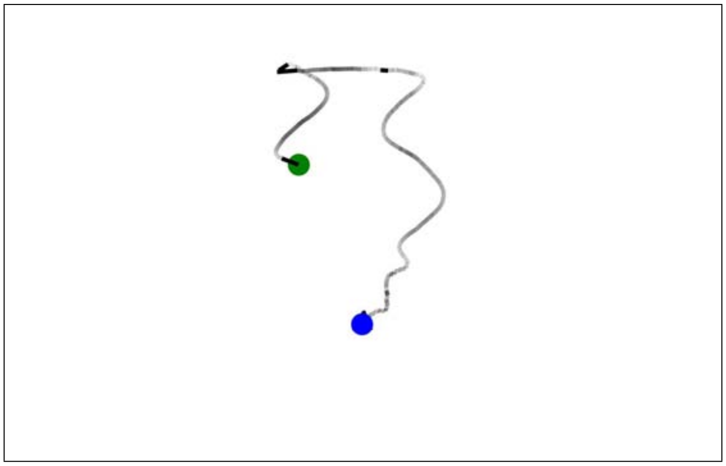

Figure 37: Example of wave like path of a tracked user.

Observations indicate that users would try to compensate for this effect - primarily a problem with position interaction because users had control over horizontal movement with motion interaction - by walking slower and in the opposite direction of the swaying, or even stop if they got confused by the reaction.

12.4.1 Navigation tasks

Analysis of visualizations for each task and observation notes show similar user behavior for navigation tasks. If users as starting point were placed in the back center of the display they would employ a distinct two step interaction technique. Firstly they would move sideways to center the target in front of them and then they would walk directly towards it. This would exhibit a path with the two steps being perpendicular to each other, as shown in Figure 38 on page 71 and 39 on page 72[17].

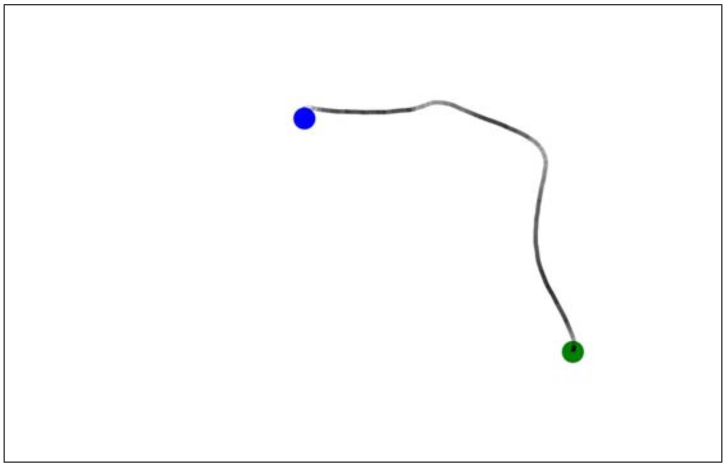

Figure 38: Example of tracked path for a navigation task using position interaction .

For motion interaction users would sometimes forget to press the button to activate tracking of sideways movement. An example of this is shown in Figure 40 on page 72. The user is seen to slow down just before the button were pressed, indicating the user, as observed, would get mildly confused or had to think about what button to press.

12.4.2 Comparison tasks

Two different behaviors were observed for comparison tasks. Firstly, if the items being compared were close enough to be showed on the display at the same time, interaction behavior were similar to that observed for navigation tasks. More interestingly, when users were asked to compare items far apart they employed a inspect-zoom-inspect technique as showed in Figure 41 on page 73. In some cases users wouldn't notice the family they needed even if it was right next to the family currently being compared and would therefore employ the same inspect-zoom-inspect technique returning them to their point of origin.

As seen, users first focused on one of the families for comparison, zooming in on that family to inspect its members. When finished inspecting the first family users

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[17] Yellow arrows indicate when the button for activating horizontal tracking were pressed (arrow down) and released (arrow up)

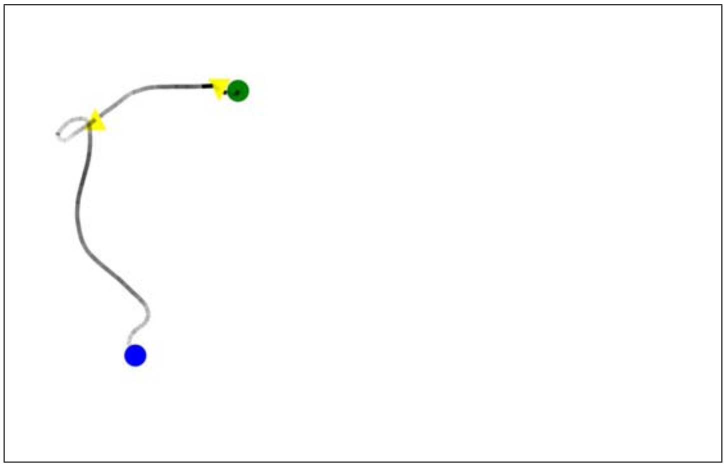

Figure 39: Example of tracked path for a navigation task using motion interaction .

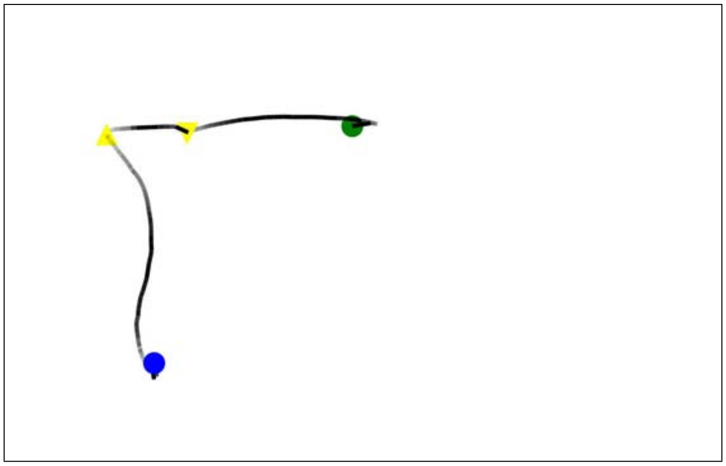

Figure 40: Example of tracked path for a navigation task using motion interaction .

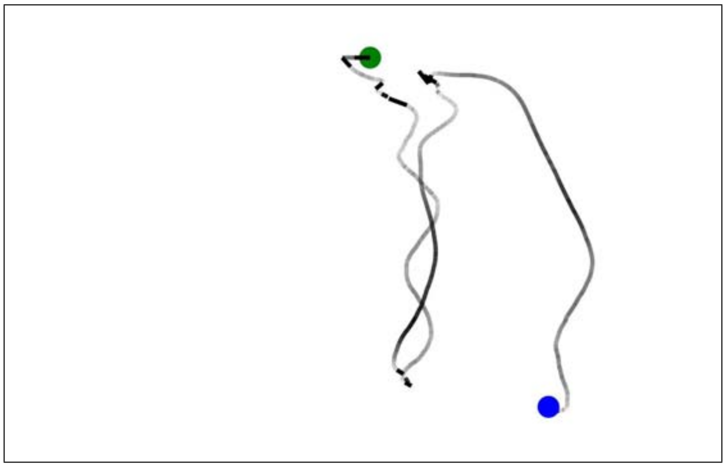

Figure 41: Example of tracked path for a comparison task using position interaction .

would move backward to zoom out and look for the second family, move sideways to center it and then walk towards the new family. This clearly shows that users felt a need to either get a better overview of the segment where the families could be found or to reduce the physical distance between families. The number of times moved between the families being compared would vary with how well the participant could remember the values and if they needed to go back to a family to select the right answer.

Evidence of the mentioned possibility to reduce physical distance between families are especially seen for motion interaction . Figure 42, for instance, shows that the user at first centered the segment on the display, inspected the first family, zoomed out, centered the second family in front of them (without activating the sideways tracking) and then walked towards the second family. That the user didn't activate the sideways tracking is a clear indication of the decreased physical distance between the families when zooming out.

Finally, as compared to Figure 41 on page 73, the total sideways distance traveled between the two families are less for position interaction than for motion interaction . This is a result caused by the user not activating the sideways tracking for motion interaction , thus preventing the visualization to come toward him.

12.4.3 Search tasks

Interaction behavior and tracked paths for search tasks are inherently more complex than navigation and comparison tasks. Similar to comparison tasks users employed a inspect-zoom-inspect strategy for comparing potential targets though the number of inspections increased as more families had to be compared. Figure 43 on page 74 shows a typical interaction pattern for a search task completed using position interaction . As can be seen multiple families have been compared as the user have walked close to the display six times.

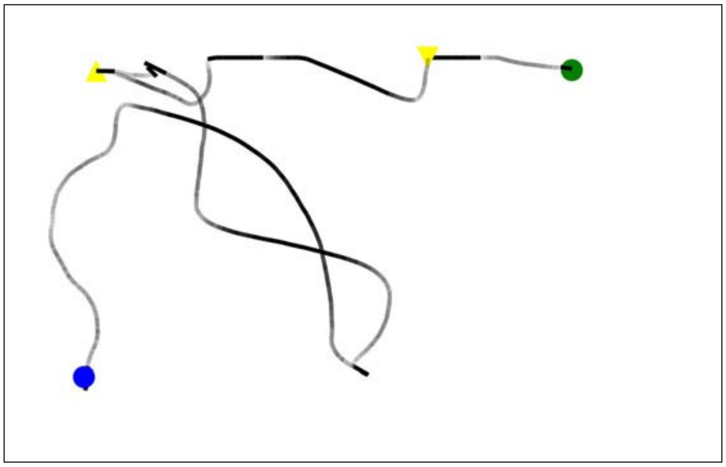

Figure 42: Example of tracked path for a comparison task using motion interaction .

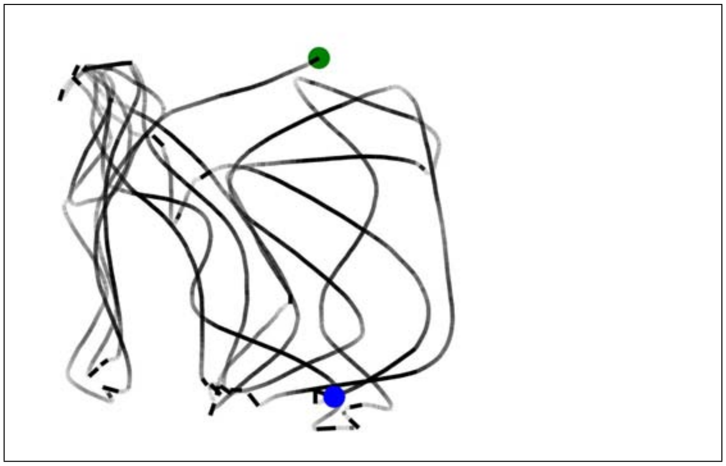

Figure 43: Example of tracked path for a search task using position interaction .

Although the tracked paths of search tasks for position interaction and motion interaction are similar, added complexity from activation and deactivation of sideways tracking for motion interaction are present. This can for instance be seen in Figure 44 on page 75.

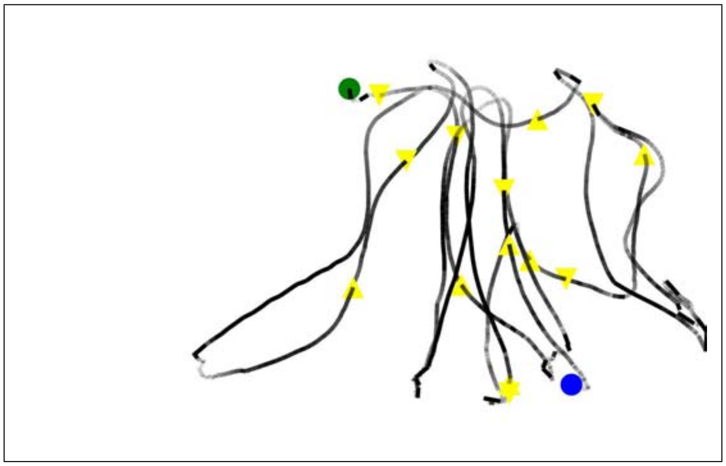

Figure 44: Example of tracked path for a search task using motion interaction .

Furthermore activation and deactivation of the button seems to happen closer to the display than compared to comparison tasks. Why this is the case is unclear.

13 Result interpretation

In the following I will provide possible interpretations of some of the results presented in section 12. Although no significant difference is seen between interaction types on average this is an interesting result in it self.

There is no clear evidence of why the interaction designs did not perform significantly different, but it is interesting to note that in spite of several reported issues with the user tracking approaches did not fall overwhelmingly behind in terms of efficiency and accuracy. This will be discussed in more detail in section 14. Some indications of the source of the differences in performance, however little it may be, is possible to derive from the collected data and observations.

Firstly, in terms of efficiency, position interaction performed better than motion interaction for navigation tasks and comparison tasks, but not for search tasks. This may be attributed to the distinct interaction patterns exhibited by participants for these three types of tasks. As reported in section 12.4 the main difference between interaction patterns for tasks were the number of times the users walked towards the display. For navigation tasks users mostly went in close one or two times, for comparison tasks two or three times, but for search tasks the count was much higher at around five to six times. Furthermore it were observed that users movement towards the screen were complicated by swaying of their body and thus their recorded position. This meant that users would get somewhat confused of the effect on the display[18] - however this isn't supported by the user questionnaire. The combination of these two factors together with the design that allowed users to control horizontal tracking with motion interaction could explain the difference. I.e. the large amount of movement towards the display for search tasks outweighed overhead from horizontal movement and thus the effect of being able to control horizontal tracking, which is complicated by swaying, leads to the observed difference in performance.

Although no clear evidence exist, a performance gain for the user tracking approaches could be further improved as they posed high cognitive loads on the users. This claim is somewhat supported in the collected data:

Firstly, several technical issues of the implementation hindered users in interacting with the system as fluidly and naturally than might be possible. This is discussed in more details in section 14.1.

Secondly, regular interaction was highly dependent on the gyro mouse so correlation between users experience with using a mouse and task completion times could be expected. This is also the case at $r = .50$ and $p = .035$. No correlation between mouse experience and task completion times was found for position interaction or motion interaction indicating that, as expected, other factors are more important with these approaches. I.e. users were better trained for regular interaction to begin with because they had experience using a mouse.

Furthermore users rated regular interaction better than motion interaction and position interaction in terms of how easy targets were to locate, how easy the data were to overview and how easy the data were to understand.

Also, the average accuracy of the user tracking interactions was lover than for position interaction - although not significantly. Regular interaction was 98% accurate, position interaction was 97% accurate and motion interaction was 93% accurate.

Finally, analysis of correlations between user preference and completion times shows no significant results in general. However, a slight relationship between if users felt that enough time were available for learning the interaction method and task completion times were observed for the two user tracking techniques ($r = -.446$ and $p = .064$ for motion interaction and $r = .432$ and $p = .073$ for motion interaction [19]).

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[18] People normally do not notice that their upper body actually sways a little when they walk and seeing it manifested in waving horizontal movement on the display is unnatural.

[19] The observed correlation is inverse because of the differences in scales - for questionnaires higher scores means better, but for completion times lower scores mean better

Part IV

Discussion, conclusion and future work

These final sections of the report aim to discuss and conclude on the work carried out and the results found. Furthermore some guidelines for future work and easy ways of making the tested system better will be suggested.

14 Discussion

The reported insignificant differences between the three interaction methods presented and tested in this report calls for a discussion of design choices for both the experiment and interaction methods.

As noted previously several technical issues possibly hindered the two user tracking approaches from exploiting their full potential. These issues and suggestions for improvements are discussed in more detail in section 14.1.

Contrary to issues with the technical implementation, I argue that the experiment design was sound. The simple tasks and clear separation of time recorded for reading and understanding tasks allowed for the reported results to be based solely on the performance of the interaction designs. The participants also expressed that the visualization was easy to understand indicating that the data set and its visualization were not a source of problems. However, the amount of time users had to learn and work with the techniques could benefit from being increased. Though, this is not supported by the questionnaire where participants rated the amount of time available for learning as well as how hard it were to learn. Linear regression analysis of the task completion times did not show significant increased performance over time for participants (R^2 varying from .003 to .048), however this can be a result of too few tasks and thus not a actual indication of learnability[20].

Looking back at the hypotheses presented in section 11.1 there is only clear evidence to confirm or reject some of them. In the following I will discuss the five hypotheses separately.

H1 *Users will find the developed interaction methods more engaging and fun to use.* This hypothesis seems to be somewhat confirmed. In the informal interviews four participants expressed that regular interaction were tedious and felt like a chore and five participants reported that it was easier to maintain concentration while using position interaction and motion interaction because they were moving and staying active. Furthermore the user tracking approaches scored higher in terms of how fun it was to use, although not significantly.

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[20] For search tasks the unstandardized coefficients are even positive (0.66 to 1.78) indicating that more time spend on search tasks leads to slower performance. This can however be attributed to there only being three search task per participant and that the last search task were harder than the first

H2 *Users will find the developed interaction methods natural and employ natural physical movements for interaction.* Results show no conclusive evidence to reject or confirm this hypothesis. As described in section 12.4 users employed a step-wise interaction pattern maintaining primarily strict sideways or forward and backward trajectories. I argue that walking straight toward a given target, as the system supported and as one would do in real life of no obstacles were in the way, would be more natural. It seems that primarily technical issues hindered users in doing this. However, the use of sideway movement for horizontal panning and the use of distance to the display as the level of magnification seemed to work for the users as observations indicate.

H3 *Explorative tasks will be performed faster using the developed interaction methods.* This hypothesis is, although not statistically significant, supported for by the results from search tasks. Results show that participants using regular interaction were 4.5% slower than when using position interaction and 13.4% slower than when using motion interaction .

H4 *For goal oriented tasks regular interaction will have higher efficiency than the user tracking techniques.* This hypothesis, although not significantly, holds for navigation tasks which were tasks performed in 17.03 seconds for regular interaction , 18.00 seconds for position interaction and 19.91 seconds for motion interaction . However for comparison tasks position interaction performed best with average task completion times at 33.6 seconds versus 35.1 seconds for regular interaction and 38.1 seconds for motion interaction .

H5 *Users will move significantly less when using regular interaction.* Although position logs for regular interaction were corrupted this hypothesis is supported by observations which indicate that only a few participants moved at all when using regular interaction .

14.1 Suggestions for improving user tracking interaction

As noted in section 12.3.1 users reported a lot of technical issues with the implemented system that could cause efficiency loss for the two user tracking interaction methods. Issues with hot zones, loss of tracking, frame rate and inconvenient tracking of their head potentially means that the techniques did not exploit their full potential. I argue that a more robust implementation as well as technical setup would result in better performance of the novel techniques and thus potentially outperform regular interaction . In the following I provide suggestions for improving the design as well as implementation of the system.

The hardware and software implementation for user tracking allows for much improvement. As pointed out through this report there is several issues with the current implementation. The following are examples of such issues:

1. The coverage of the web camera are somewhat limited resulting in a small tracking area .

2. Using a ultra-wide angle web camera causes perspective distortion of the recorded image.
3. The web camera used provided a limited frame rate at 30 frames per second.
4. The color filtering technique was highly dependent on lighting conditions staying the same during use.

By employing a different approach to user tracking, such as tracking of RFID tags[21], a larger area could be covered with ease. Furthermore the tag could be placed anywhere on the users body allowing for the user to move more freely and not experiences issues caused by swaying of their upper body. I argue that these fundamental aspects of a user tracking system needs to be taken care of to allow the user to experience a closer relationship between movement and the effect on the display thus exploiting their embodied resources. Furthermore a larger display would create a greater need for an efficient information visualization technique because objects on the display would become increasingly distorted the further away from the user.

Many of the participants also expressed concerns or confusion about the design of the hot zones. The problems are mainly caused by the instant change from not scrolling to scrolling. Although a delay before starting the automatic scrolling were implemented users did not notice the yellow indication arrow and therefore got surprised when the visualization started moving on itself. A solution to this could be the graduated hot zones described in 7.4.1 as well as a more clear indication of scrolling is about to start. The indicator could gradually appear and scrolling speed up as users moved closer to edges. This way users can control scrolling more precisely as well as stop it before moving too far.

15 Future work

In this project I have mainly focused on single user interaction for wall-size displays. However, as the literature also suggests, large displays are especially usable for collaborative work.

It could be interesting to see how collaborative work could benefit from tracking of multiple users, but also how the interaction paradigms presented in section 7 could be customized to work with two or more simultaneous users.

As presented in this report, user tracking interaction has been defined as a mapping between a single user in the physical space and the whole of the virtual space. However, how should these spaces be shared for multiple users. The basic interaction patterns as scrolling and zooming are suddenly broken in the multi user scenario; how do you define the zoom level if one user is close to the display and the other far from the display, if one user moves what does it mean - does his movement change the viewport for the second user, etc. These are interesting but non trivial questions to answer, and it is an obvious theme for future research.

For the information visualization techniques presented in section 8 some could easily work in a multi user configuration. The information lenses are only defined as a

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[21] Similar to the Ubisense system described in section 6

region in front of a user, and thus multiple regions could exist. Furthermore it would be interesting to explore the possibilities of overlapping information lenses for collaborative work. Should overlapping result in filters being combined for deeper filtering or should both sets of data be shown?

Furthermore, as suggested by [19] and my study, physical interaction seems to work best for explorative tasks. Future research should try to understand why his is the case. Also future research could benefit from developing and testing techniques for exploring data as this seems fit best with physical interaction.

Finally future research need to study the long term effects of physical interaction. Issues such as learnability and physiological effects are not well understood and needs to be uncovered.

16 Conclusion

In this report I have presented a design and empirical study of two novel approaches to interaction design for wall-size displays. Contrary to previous research in this area my approach employs user tracking as a main method of navigation. By mapping users movement and position in physical space to the virtual space represented by the display the aim is to utilize users' embodied resources to increase efficiency, accuracy and satisfaction.

Two approaches for user tracking interaction are proposed. Both approaches maps sideways movement in physical directly to virtual space and motion toward the display as increase in magnification. One denoted position interaction utilizes the users position relative to the display for determining what area of the virtual space is visible. To allow the user to access a larger virtual space than accessible via direct mapping from physical space hot zones for automatic scrolling in the left and right edge have been implemented. The second approach denoted motion interaction uses state dependent sideways tracking; i.e. tracking are only enabled for sideways movement when the user explicitly enables it by pressing a button. This allows the user to be in greater control of horizontal panning as well as access non-direct mappable areas of the virtual space by employing a move-reset-move technique known from computer mice.

Because of perspective distortion experienced by the user when being close to the display a scale correction visualization technique were employed. This meant that virtual objects far from the user were increased in size to maintain constant visual acuity.

To test the usability of these novel approaches a relational empirical study has been carried out. Users solved navigation, comparison and search tasks in a visualization of a social network of families and family members using the two user tracking approaches as well as with a gyroscopic mouse for baseline results. Eighteen participants performed a total of 15 tasks with each of the interaction methods as well as answering questionnaires for user satisfaction.

Results are somewhat inconclusive and of high variability. No significant difference in average task completion time, accuracy or user satisfaction were measured. Analysis suggest that technical issues with the implementation hindered the two user tracking approaches from exploiting their full potential. Furthermore might the short duration of experiments and introduction for each interaction type have held participants from reaching an adequate level of experience to gain full potential from their embodied resources.

Future research should focus on ensuring a robust technical implementation for user tracking as well as extending the duration of experiments to allow participants to get more acquainted with the interaction designs. Finally interaction design and information visualization for wall-size displays in the context of multiple users are a large unexplored area that could benefit hugely from user tracking.

17 Konklussion (Danish)

I denne rapport har jeg præsenteret et design af et empirisk studie af to nye tilgange til interaktionsdesign for meget store skærme. I modsætning til tidligere forskning i området bruger mine designs brugersporing som den primære måde at navigere på. Målet er, ved at afbilde brugernes bevægelse og position i fysisk rum til det virtuelle rum, repræsenteret af skærmen, at udnytte brugernes naturlige kropslige ressourcer til at øge effektiviteten, præcisionen og tilfredsheden.

To tilgange til brugersporingsinteraktion er foreslået. Begge tilgange afbildede sidelæns bevægelse i fysisk rum til sidelæns bevægelse i det virtuelle rum. Endvidere blev bevgelse frem og tilbage udnyttet til at bestemme zoomniveauet i det virtuelle rum. Den ene tilgang, kaldt positionsinteraktion, udnytter brugernes position i forhold til skærmen til at afgøre hvilket område af det virtuelle rum som er synligt. For at gøre det muligt for brugeren at tilgået større virtuelt rum end tilgængeligt via direkte afbildning fra det fysiske rum er der i venstre og højre side af det sporede område implementeret aktiveringsområder til automatisk rulning. Den anden interaktionsteknik, kaldet bevægelsesinteraktion, benytter tilstandsafhængig sidelæns sporing; dvs. sporing er kun aktiveret for sidelæns bevægelser når brugeren eksplicit aktiverer det ved at trykke påen knap. Dette tillader brugeren at have bedre kontrol over horisontal panorering samt at tilgåområder i det virtuelle rum som ikke kan nås med direkte afbildning. Det sker ved at benytte en flyt-genstart-flyt teknik kendt fra computermus.

Grundet perspektivforvrængning oplevet af brugerne når de er tæt påskærmen er der implementeret en visualisering som benytter størrelseskorrektion. Dette betyder at virtuelle objekter som er langt fra brugeren er forstørret for at vedligeholde en konstant visuel skarphed.

For at vurdere brugsvenligheden af disse to nye tilgange er der gennemført et relationelt empirisk studie. Deltagere løste navigations-, sammenlignings- og søgeopgaver i en visualisering af et socialt netværk af familier og familiemedlemmer ved brug af de to brugersporingsteknikker samt en gyroskopisk mus som kontroltilfælde. I alt gennemførte 18 deltager 15 opgaver med hver af de tre interaktionsmetoder. Desuden besvarede de spørgeskemaer om brugertilfredshed.

Resultaterne er ikke entydige og med høj varians. Der er ingen signifikant forskel i gennemsnitlig opgaveudførelsestid, præcision eller brugertilfredshed blev målt. Analyse af resultaterne indikere at tekniske problemer med implementationen af systemet forhindrede de to brugersporingsteknikker i at leve op til deres fulde potentiale. Endvidere lader det til at den korte varighed af eksperimenterne og introduktionerne holdte forsøgsdeltagerne fra at nået tilstrækkeligt niveau af erfaring for at kunne drage fordel af deres naturlige kropslige ressourcer.

Fremtidig forskning bør fokusere påat sikre en robust teknisk implementering af brugersporing samt at forøge varigheden af eksperimenterne for at tillade de deltagende at blive mere bekendte med interaktionsdesignet. Endeligt er interaktionsdesign og informationsvisualisering i konteksten af kmpe skærme et stort uudforsket om råde som i høj grad kan drage fordel af brugersporing.

18 Acknowledgments

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Part V
Appendix

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A GraecoLatin squares used in experiment design

Below is the graeco latin squares used for the experiment design described in section 11. The abbreviations are:

- R - Regular interaction
- M - Movement interaction
- P - Position interaction

The numbers 1-3 are task sets 1 through 3.

$$\begin{pmatrix} P2 & M1 & R3 \\ M3 & R2 & P1 \\ R1 & P3 & M2 \end{pmatrix}$$

$$\begin{pmatrix} P3 & M2 & R1 \\ M2 & R1 & P3 \\ R1 & P3 & M2 \end{pmatrix}$$

$$\begin{pmatrix} M3 & P1 & R2 \\ R1 & M2 & P3 \\ P2 & R3 & M1 \end{pmatrix}$$

$$\begin{pmatrix} P1 & R2 & M3 \\ R2 & M3 & P1 \\ M3 & P1 & R2 \end{pmatrix}$$

$$\begin{pmatrix} P2 & M3 & R1 \\ M1 & R2 & P3 \\ R3 & P1 & M2 \end{pmatrix}$$

$$\begin{pmatrix} M1 & R3 & P2 \\ P2 & M1 & R3 \\ R3 & P2 & M1 \end{pmatrix}$$

B Task sets

B.1 Task set 1

1. Navigate - Find the Hart family. (introduction task)
2. Navigate - In the Bishop family, find the vegetarian. (introduction task)
3. Compare - Among the Anders and James families, find the person who is the tallest. (introduction task)
4. Compare - Among the Brooks and Kelly familes, find the person who earns the most. (introduction task)
5. Navigate - Find Evan Day. (introduction task)
6. Navigate - Find the Cooper family. (introduction task)
7. Search - Among the families directly connected to the Mitchell family, find the programmer who earns the least. (introduction task)
8. Search - Among the families starting with H in the green segment, find the person without a car who earns the most. (introduction task)
9. Navigate - Find Sarah Kennedy.
10. Navigate - In the Bruce family, find the person who is a pilot.
11. Navigate - In the Brown family, find the person who drives a Ford.
12. Navigate - Find the Walker family.
13. Compare - Among the Fisher and Arnold families, find the person who is the tallest.
14. Navigate - In the Mason family, find the person who is an accountant.
15. Search - Among the families starting with F in the orange segment, find the vegetarian with the least children.
16. Compare - Among the Jackson and Johnson familes, find the person who earns the least.
17. Navigate - Find Emma Hawkins.
18. Search - Among the families directly connected with the Day family, find the school teacher with the most children.
19. Navigate - Find the Powell family.
20. Compare - Among the Riley and Ward families, find the person who is the tallest.
21. Navigate - In the Armstrong family, find the person without a car.

22. Compare - Among the Peters and Clark families, find the person who earns the most.
23. Search - Among the families starting with R in the purple segment, find the cab driver who is the tallest.

B.2 Task set 2

1. Navigate - Find the Rose family. (introduction task)
2. Navigate - In the Jordan family, find the person who is a programmer. (introduction task)
3. Compare - Among the Barker and Rose families, find the person who earns the most. (introduction task)
4. Compare - Among the Robinson and Miller families, find the person who is the tallest. (introduction task)
5. Navigate - Find Evan Burns. (introduction task)
6. Navigate - Find the Owens family. (introduction task)
7. Search - Among the families directly connected with the Watts family, find the pilot who earns the most. (introduction task)
8. Search - Among the families starting with P in the green segment, find the programmer with the most children. (introduction task)
9. Navigate - Find the Matthews family.
10. Navigate - In the Black family, find the person without a car.
11. Navigate - In the Tucker family, find the person who drives a Chrysler.
12. Navigate - Find Morgan Parker.
13. Compare - Among the Hughes and Simmons families, find the person who is the tallest.
14. Navigate - In the Jordan family, find the person who is a vegetarian.
15. Search - Cameron Sullivan; Among the families directly connected with the Rose family, find the school teacher who is the tallest.
16. Compare - Among the Ellis and Gibson families, find the person who earns the most.
17. Navigate - Find Bryan Crawford.
18. Search - Among the families starting with B in the blue segment, find the shortest person who drives a Ford.

19. Navigate - Find the Lee family.
20. Compare - Among the Jenkins and Brooks families, find the person who earns the most.
21. Navigate - In the King family, find the person who is a cashier.
22. Compare - Among the Sullivan and Collins families, find the person who is the shortest.
23. Search - Among the families starting with W in the orange segment, find the tallest vegetarian.

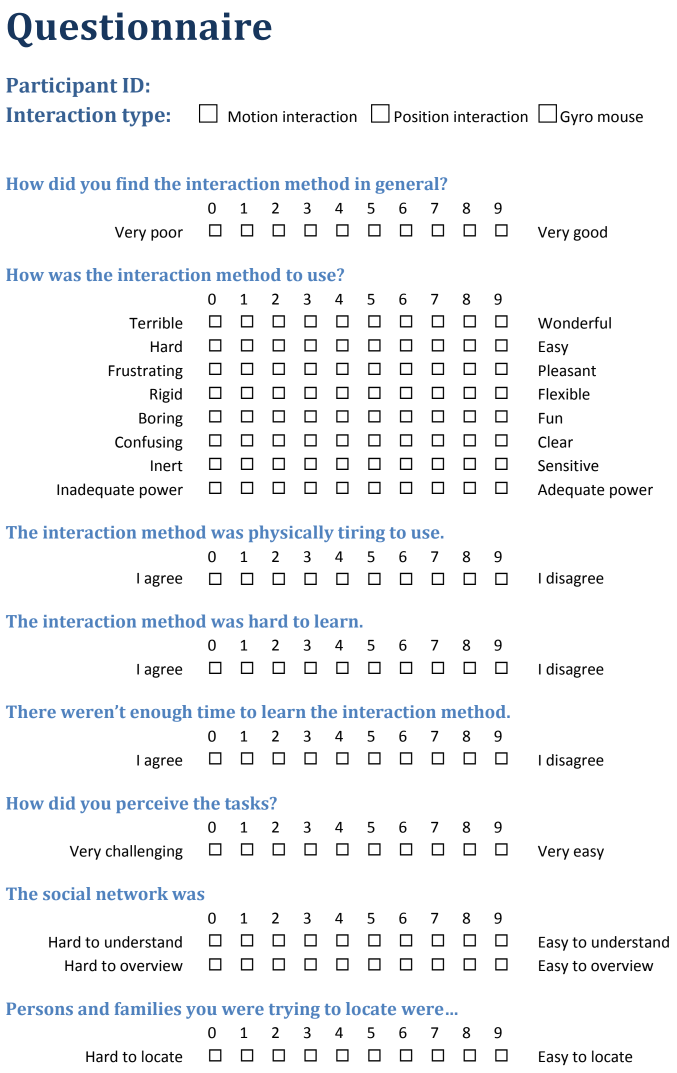
B.3 Task set 3

1. Navigate - Find the Dixon family. (introduction task)
2. Navigate - In the Elliott family, find the person who is a programmer. (introduction task)
3. Compare - Among the Smith and Little families, find the person who is the tallest. (introduction task)
4. Compare - Among the Bailey and Owens families, find the person who earns the most. (introduction task)
5. Navigate - Find Vanessa Brown. (introduction task)
6. Navigate - Find the Wells family. (introduction task)
7. Search - Among the families starting with R in the orange segment, find the pilot who earns the most. (introduction task)
8. Search - Among the families directly connected to the York family, find the vegetarian who is the shortest. (introduction task)
9. Navigate - Find Maria Roberts.
10. Navigate - In the Mitchell family, find the person who drives a Camero.
11. Navigate - Find the Edwards family.
12. Navigate - In the Arnold family, find the person who is an accountant.
13. Compare - Among the Moore and Stewart families, find the person who is the shortest.
14. Navigate - In the Shaw family, find the person who is a vegetarian.
15. Search - Among the families directly connected to the Wirick family, find the school teacher who earns the most.

16. Compare - Among the Arnold and Boyd families, find the person who earns the most.
17. Navigate - Find Emma Reynolds.
18. Search - Among the families starting with W in the blue segment, find the vegetarian with the least children.
19. Navigate - Find Ethan Peters.
20. Compare - Among the Steele and Gray families, find the person who is the tallest.
21. Navigate - In the Holland family, find the person who drives a Ford
22. Compare - Among the Crawford and Green families, find the person with the least children.
23. Search - Among the families starting with D in the green segment, find the architect who is the tallest.

C Questionnaires

D Written introduction



Questionnaire

Participant ID:

Interaction type: ☐ Motion interaction ☐ Position interaction ☐ Gyro mouse

How did you find the interaction method in general?

	0	1	2	3	4	5	6	7	8	9	
Very poor	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Very good

How was the interaction method to use?

	0	1	2	3	4	5	6	7	8	9	
Terrible	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Wonderful
Hard	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Easy
Frustrating	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Pleasant
Rigid	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Flexible
Boring	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Fun
Confusing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Clear
Inert	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Sensitive
Inadequate power	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Adequate power

The interaction method was physically tiring to use.

	0	1	2	3	4	5	6	7	8	9	
I agree	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	I disagree

The interaction method was hard to learn.

	0	1	2	3	4	5	6	7	8	9	
I agree	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	I disagree

There weren't enough time to learn the interaction method.

	0	1	2	3	4	5	6	7	8	9	
I agree	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	I disagree

How did you perceive the tasks?

	0	1	2	3	4	5	6	7	8	9	
Very challenging	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Very easy

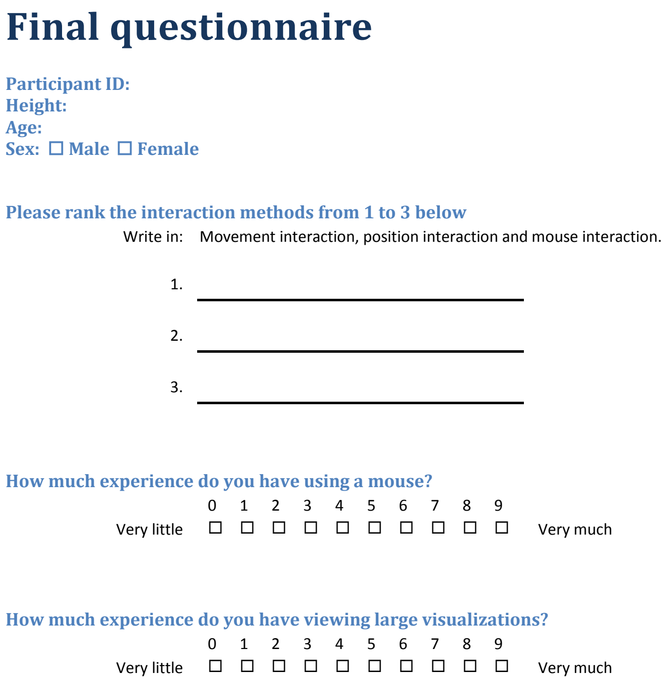
The social network was

	0	1	2	3	4	5	6	7	8	9	
Hard to understand	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Easy to understand
Hard to overview	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Easy to overview

Persons and families you were trying to locate were…

	0	1	2	3	4	5	6	7	8	9	
Hard to locate	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Easy to locate

Figure 45: Questionnaire.



Final questionnaire

Participant ID:
Height:
Age:
Sex: ☐ **Male** ☐ **Female**

Please rank the interaction methods from 1 to 3 below

Write in: Movement interaction, position interaction and mouse interaction.

1. ______________________________
2. ______________________________
3. ______________________________

How much experience do you have using a mouse?

	0	1	2	3	4	5	6	7	8	9	
Very little	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Very much

How much experience do you have viewing large visualizations?

	0	1	2	3	4	5	6	7	8	9	
Very little	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Very much

Figure 46: Final questionnaire.

Introduktion til eksperiment om interaktion med store skærme

Eksperimentet du nu skal deltage i er opdelt i seks faser

1. Introduktion (den er du i gang med nu)
2. Kalibrering
3. Første del af eksperimentet (efterfulgt af kort spørgeskema)
4. Anden del af eksperimentet (efterfulgt af kort spørgeskema)
5. Tredje del af eksperimentet (efterfulgt af kort spørgeskema)
6. Afslutning

Hver del af eksperimentet består af en introduktion til den grænseflade og den interaktionsform du skal til at bruge. Du får en række introduktionsspørgsmål som giver dig mulighed for at øve dig i hvordan systemet fungerer. Under introduktionsspørgsmålene opfordres du til at udforske interaktionsformen indtil du føler dig tryg ved den.

Efter introduktionsspørgsmålene starter den rigtige del af eksperimentet. Her skal du løse opgaverne så hurtigt og præcist som det er dig muligt.

Imellem hver del af eksperimentet skal du udfylde et kort spørgeskema om din oplevelse af systemet og til sidst er der et afsluttende spørgeskema.

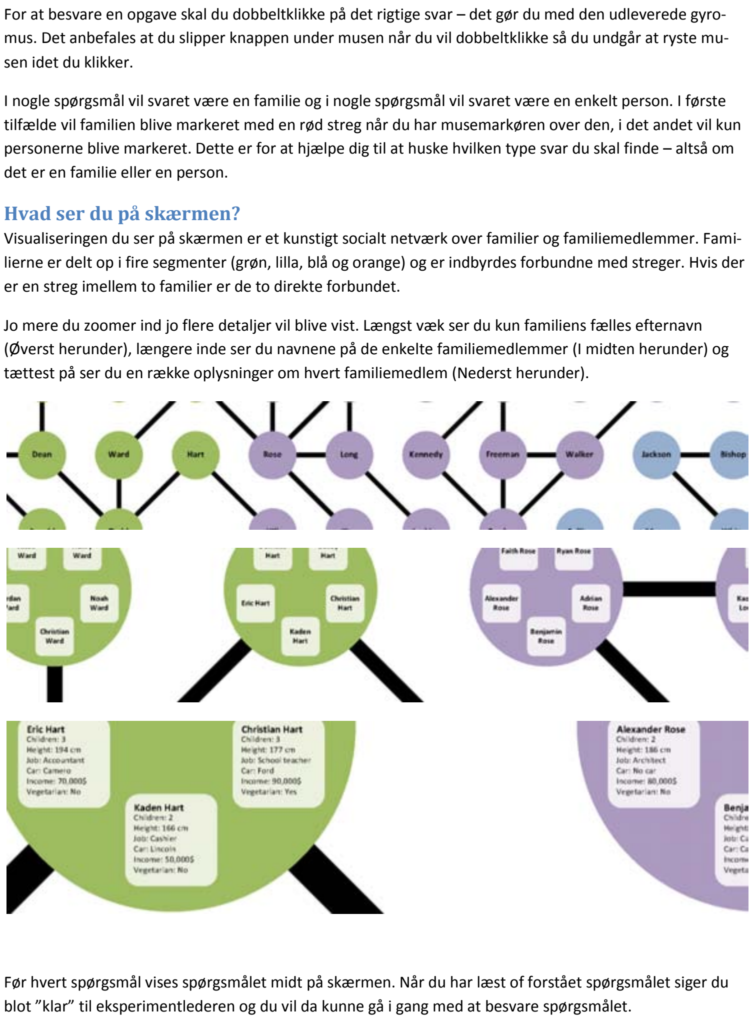
Gyro-mus

I alle dele af eksperimentet skal du bruge en mus som du får udleveret. Det er en såkaldt gyromus som du kan bruge i luften.

For at bevæge musemarkøren skal du holde knappen under musen (den lige ved din pegefinger) inde. Når du holder knappen inde følger musen dine bevægelser. Hvis ikke knappen er holdt inde bevæger musemarkøren sig ikke. Se billedet herunder:

Knappen du skal holde inde for at musemarkøren bevæger sig.

Figure 47: Written introduction - page 1.



For at besvare en opgave skal du dobbeltklikke på det rigtige svar – det gør du med den udleverede gyromus. Det anbefales at du slipper knappen under musen når du vil dobbeltklikke så du undgår at ryste musen idet du klikker.

I nogle spørgsmål vil svaret være en familie og i nogle spørgsmål vil svaret være en enkelt person. I første tilfælde vil familien blive markeret med en rød streg når du har musemarkøren over den, i det andet vil kun personerne blive markeret. Dette er for at hjælpe dig til at huske hvilken type svar du skal finde – altså om det er en familie eller en person.

Hvad ser du på skærmen?

Visualiseringen du ser på skærmen er et kunstigt socialt netværk over familier og familiemedlemmer. Familierne er delt op i fire segmenter (grøn, lilla, blå og orange) og er indbyrdes forbundne med streger. Hvis der er en streg imellem to familier er de to direkte forbundet.

Jo mere du zoomer ind jo flere detaljer vil blive vist. Længst væk ser du kun familiens fælles efternavn (Øverst herunder), længere inde ser du navnene på de enkelte familiemedlemmer (I midten herunder) og tættest på ser du en række oplysninger om hvert familiemedlem (Nederst herunder).

Eric Hart
Children: 3
Height: 194 cm
Job: Accountant
Car: Camero
Income: 70,000$
Vegetarian: No

Christian Hart
Children: 3
Height: 177 cm
Job: School teacher
Car: Ford
Income: 90,000$
Vegetarian: Yes

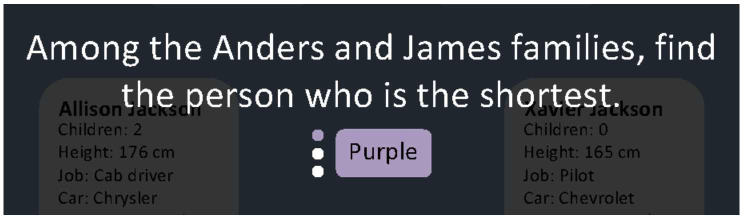
Kaden Hart
Children: 2
Height: 166 cm
Job: Cashier
Car: Lincoln
Income: 50,000$
Vegetarian: No

Alexander Rose
Children: 2
Height: 186 cm
Job: Architect
Car: No car
Income: 80,000$
Vegetarian: No

Før hvert spørgsmål vises spørgsmålet midt på skærmen. Når du har læst of forstået spørgsmålet siger du blot ”klar” til eksperimentlederen og du vil da kunne gå i gang med at besvare spørgsmålet.

Figure 48: Written introduction - page 2.

Når et spørgsmål bliver vist er der samtidig en indikator af hvor du kan finde svaret, så du har nemmere med at finde ud af hvor du skal lede. Denne indikator vil stå lige nedenunder spørgsmålet – se f.eks. herunder:


Among the Anders and James families, find the person who is the shortest.

Allison Jackson
Children: 2
Height: 176 cm
Job: Cab driver
Car: Chrysler

Xavier Jackson
Children: 0
Height: 165 cm
Job: Pilot
Car: Chevrolet

Farven angiver i hvilket segment du skal kigge, og cirklerne angiver om svaret er placeret i den øverste halvdel, i midten eller i den nederste halvdel af segmentet.

Når du er i gang med at besvare spørgsmålet vil spørgsmålteksten og indikatoren altid være synlig øverst på skærmen – se herunder:


Among the Anders and James families, find th

Height: 150 cm
Job: Programmer
Car: Chevrolet
Income: 120,000$

Height: 153 cm
Job: Cab driver
Car: Lincoln
Income: 80,000$

Interaktion med gyromusen

I den ene del af eksperimentet skal du kun bruge musen. For at navigere rundt i det sociale netværk kan du zoome og panorere.

For at panorere skal du holde venstre museknap nede og flytte musen. Så tager den fat i netværket og flytter det (husk også at holde knappen under musen nede).

For at zoome skal du holde højre museknap nede og flytte musen mod højre (zoome ud) eller venstre (zoome ind). Hvis du gerne vil zoome ind på en bestemt person eller familie skal du huske at placere musemarkøren ovenover inden du begynder at holde højre museknap nede.

Interaktion med dig selv

I to dele af eksperimentet skal du bruge dig selv til at interagere med systemet.

De to systemer virker på lidt forskellige måder, men de reagerer begge på dine bevægelser. For at zoome ind skal du blot gå tættere på skærmen, og for at zoome ud skal du gå længere væk. Måden hvorpå du pa-

Figure 49: Written introduction - page 3.

norere til siderne er forskellige for de to systemer og vil blive beskrevet senere; fælles er det dog at tingene du ser på skærmen så at sige komme dig i møde når du går hen imod dem– altså når du går mod venstre flytter tingene på skærmen sig til højre.

Fælles for de to måder er desuden at for at panorere op og ned i netværket skal du bruge musens scrollhjul.

Interaktion med din bevægelse

I en del af eksperimentet skal du interagere med systemet ved brug af dig selv og dine bevægelser.

For at panorere til siden skal du holde højre museknap inde og bevæge dig. Hvis du gør dette registrer systemet dine bevægelser og panorerer på grundlag heraf. Systemet vil kun panorere når du holder denne knap inde. Hvis du gerne vil længere til en af siderne end du kan bevæge dig skal du blot slippe knappen og gå over til den anden side af skærmen og så gentage din bevægelse – ligesom du gør med en mus når du løfter den og sætter den et andet sted, hvis du er løbet tør for plads på bordet.

Interaktion med din position

I en del af eksperimentet skal du interagere med systemet ved brug af dig selv og din placering på gulvet.

For at panorere skal du blot gå til en af siderne. Du skal i denne del ikke holde en knap inde for at systemet registrere dine bevægelser til siderne.

Hvis du stiller dig i en af siderne af bevægelsesområdet (omtalt senere) vil systemet begynde at rulle til den side efter et kort stykke tid. Når du står i sådan et område vil der komme en pil i den side af skærmen du står i. Pilen vil være gul indtil du har stået der et kort stykke tid hvorefter den vil blive grøn og systemet vil panorere automatisk.

Bevægelsesområdet

Af tekniske årsager er det område du kan bevæge dig på i denne del af eksperimentet begrænset. Området er afmærket på gulvet. Du skal så vidt muligt prøve at holde dig inden for dette område.

Kalibrering

Inden eksperimentet kan starte skal vi have kalibreret systemet så det kan finde din position. Du skal blot følge eksperimentlederens instruktioner her.

Figure 50: Written introduction - page 4.