

Institute for Visualization and Interactive Systems

University of Stuttgart  
Universitätsstraße 38  
D-70569 Stuttgart

Masterarbeit

# **Content Arrangement on Large High-Resolution Displays: A PDF-Reader**

Onur Aydin

**Course of Study:** INFOTECH

**Examiner:** Prof. Dr. Albrecht Schmidt

**Supervisor:** Dipl.-Inf. Lars Lischke,  
Dr. Paweł W. Woźniak

**Commenced:** May 3, 2017

**Completed:** November 3, 2017

**CR-Classification:** H.5.2



## Abstract

The advent of Large High Resolution Displays (LHRDs) enables new visualisation methods for data analysis. This allows users to replace virtual navigation with spatial navigation which leads to further challenges in arranging the content appropriately. Conventional applications are developed without considering these novel issues; thus they may have deficiencies to be used on LHRDs efficiently. For this purpose, we conduct this thesis with a focus on the content arrangement of PDF documents. The aim of this thesis is to design, implement and evaluate an interface for viewing PDF documents on LHRDs. After an extensive literature review, we conducted design workshops to elicit design concepts and received various inspiring suggestions. The most promising design ideas were implemented as a working prototype by using an existing open source PDF renderer. Finally, we evaluated our implementation in a collaborative sensemaking user study in terms of usability and performance. We examine the result of the evaluation study and present key influencing factors which might be useful for future applications on LHRDs.





# Contents

1	Introduction	13
2	Related Work	17
2.1	Content Management and Document Navigation . . . . .	17
2.2	Cognitive Effects . . . . .	19
2.3	Interaction . . . . .	20
2.4	Large Display Workspaces . . . . .	21
2.5	Methodology . . . . .	22
2.6	Influences of LHRDs on Performance . . . . .	23
3	GUI Design Elicitation Study	25
3.1	Methodology . . . . .	25
3.2	Analysis of Results . . . . .	27
4	Implementation	41
4.1	Development Tools . . . . .	41
4.2	Core Functionality . . . . .	42
4.3	Architecture . . . . .	43
4.4	Design Considerations . . . . .	43
4.5	General View . . . . .	51
5	Evaluation	53
5.1	Demographics . . . . .	53
5.2	Apparatus . . . . .	54
5.3	Methodology . . . . .	55
5.4	Results and Analysis . . . . .	60
5.5	Limitations . . . . .	65
5.6	Discussions . . . . .	66
6	Conclusion	69
6.1	Future Work . . . . .	70
	Bibliography	71



# List of Figures

3.1	General view of the set-up during a workshop . . . . .	27
3.2	Scroll button interface . . . . .	29
3.3	Aggregated view of related works . . . . .	30
3.4	Additional overview on the top . . . . .	31
3.5	Linked relationship between related works . . . . .	31
3.6	Focus and overview areas . . . . .	32
3.7	Text editor . . . . .	33
3.8	Built-in browser . . . . .	34
3.9	Annotations for the publication date . . . . .	34
3.10	Removing an irrelevant page . . . . .	35
3.11	Movable references page . . . . .	35
3.12	Interactive interaction with the content . . . . .	36
4.1	UML diagram . . . . .	44
4.2	Different layout styles . . . . .	45
4.3	Context menu . . . . .	47
4.4	Text editor . . . . .	48
4.5	Integrated web browser . . . . .	49
4.6	Text search . . . . .	50
4.7	A general view of a working prototype . . . . .	51
5.1	Study materials: LHRDs, consent forms, pens, round table, wireless keyboard and mouse . . . . .	55
5.2	Collection of the dataset . . . . .	56
5.3	Mean values of TCTs with standard deviations . . . . .	60
5.4	Mean values of NASA TLX scores . . . . .	61
5.5	Mean values of System Usability Scale (SUS) scores . . . . .	62
5.6	Mean values of sum of the mouse-drag distance in pixels . . . . .	62
5.7	Mean values of total number of mouse clicks in both conditions . . . . .	63
5.8	Typical layout in <i>Condition B</i> . . . . .	64
5.9	The pages below eye level <i>Condition A</i> . . . . .	65
5.10	Grouping of the supporting images in <i>Condition A</i> . . . . .	66



# List of Tables

3.1	Participants' profile in the design workshops . . . . .	26
3.2	Extraction of design study results. . . . .	28
5.1	Participants in the collaborative sensemaking study . . . . .	54



# List of Abbreviations

<b>API</b>	Application Programming Interface.	14
<b>GUI</b>	Graphical User Interface.	13
<b>IRVE</b>	Information-Rich Virtual Environment.	23
<b>LHRD</b>	Large High Resolution Display.	13
<b>MDI</b>	Multiple Document Interface.	44
<b>PDF</b>	Portable Document Format.	13
<b>SUS</b>	System Usability Scale.	7
<b>TCT</b>	Task Completion Time.	14
<b>TLX</b>	Task Load Index.	14
<b>UML</b>	Unified Modeling Language.	43
<b>XML</b>	Extensible Markup Language.	42





# 1 Introduction

Through advances in display technology and computing power, Large High Resolution Displays (LHRDs) are becoming feasible for many set-ups. Such displays can provide a more detailed overview of large data sets and enable users to spread information spatially. Hence, they allow users to explore visual data more efficiently.

In the literature, there are already studies which investigate how task completion performance is affected by using LHRDs [BN05; BNB07; CSR+03; LCB+14; NBC06; TGSP03]. Their results which demonstrate that the performance is increased significantly for some specific tasks, aroused our interest to do this thesis. Another source of motivation for us was the studies which demonstrate that using LHRDs increases user satisfaction [CSR+03] and reduces cognitive load [BN05].

Despite such benefits of LHRDs, conventional Graphical User Interfaces (GUIs) do not support their physical advantages. One prominent example of this lack of support appears in document viewer applications. When using such applications, their layout capabilities are quite limited to arrange multiple documents efficiently and simultaneously.

Being one of the most popular file formats to visualise electronic documents, we chose to focus on Portable Document Format (PDF) format to investigate effects of using LHRDs for viewing digital contents. The PDF file format provides a stable layout also on LHRDs since it is a platform-independent file format which encapsulates the features of the electronic documents such as; font, layout, and graphics.

Currently, standard PDF readers are not designed considering large displays; therefore it is not possible to use them efficiently in such an environment. Resolution and dimensions ought to be taken into consideration in order to achieve usability goal of the large displays. In this thesis, we aim to develop a specific application that enables users to benefit the flexibility of using LHRDs. Our target is to enhance user experience and performance over conventional PDF readers.

Initially, we did an extensive literature research with a focus on interaction with large displays and document management. Related works which provide motivation and guidance for our study are presented in different categories.

To elicit the possible user-friendly design ideas, we conducted user-centered design workshops with twelve participants who have an occupation in academia. The focus of the design workshops was reading, reviewing scientific articles, and doing a literature research. We used paper prototyping together with a whiteboard to simulate LHRDs based on the study by Knudsen et al. [KJH12].

After analysis of the workshop results, we designed the GUI of our prototype accordingly. Both diversities and similarities of the participants' expectations are taken into consideration while trying to cover most of the ideas. The prototype is implemented as a Qt widget application and programmed in C++. We used an open source PDF-renderer, MuPDF which provides an Application Programming Interface (API) in C for rendering PDF files.

We prioritised customizability by allowing pages of a document to be moved individually, or hidden if they are not required. The pages can be zoomed, tiled horizontally, vertically, and arranged as a grid. Additionally, we implemented various features which were mentioned in the workshops such as searching a keyword, built-in browsers, and text editors.

We targeted to ensure that enhancements are achieved as we expected. For this purpose, we conducted a collaborative sensemaking study to evaluate the success of our working prototype compared to a standard PDF reader. Inspired by the previous work [WKL+16], a crime puzzle is designed to be solved by the pairs of participants. Clues of the puzzle are displayed on LHRD accompanied by some noise information. There were two conditions; *Condition A* in which pairs used our prototype to view clues, and *Condition B* in which participants explored clues with a common PDF reader.

The evaluation user study revealed that our prototype was not able to increase Task Completion Time (TCT) in contrast to our hypothesis. Besides, the prototype could not produce a significant increase in usability according to SUS scores. Although we did not receive a notable difference in task workloads regarding NASA Task Load Index (TLX) scores, our prototype almost doubled the physical demand sub-scale in comparison with the standard PDF reader. Concerning the accuracy of the answers, only one of five couples in *Condition A* and two of five pairs could come with the right answer.

We presented weaknesses of the evaluation user study in Section 5.5, and analysed possible grounds for the these results in Section 5.6.

---

## Structure

This work is structured in following way:

**Chapter 2 – Related Work:** shows previous research related to this thesis.

**Chapter 3 – GUI Design Elicitation Study:** The methodology and the results of the design workshops are presented.

**Chapter 4 – Implementation:** shows the design steps and implementation details of the prototype.

**Chapter 5 – Evaluation:** describes the user study to evaluate usability of our prototype over a standard PDF reader; the analysis is presented.

**Chapter 6 – Conclusion** summarizes the results of the work and introduces linking points.



## 2 Related Work

We review previous works in the literature under the following six categories. In Section 2.1 researches related to document management and navigation challenges of the thesis will be presented. We examine the works regarding intangible cognitive effects such as satisfaction, sense-making and spatial memory in Section 2.2. Researches related to interaction techniques for LHRDs are handled in Section 2.3. Papers that examine LHRDs within their environment with peripherals are mentioned in Section 2.4. For the workshops to be conducted in order to design a GUI for our PDF reader, works interested in user studies are introduced in Section 2.5. We discuss the studies that deal with performance improvement as a result of LHRD utilization in Section 2.6.

### 2.1 Content Management and Document Navigation

Since content management is an essential aspect of this thesis, researches related to this concept are mentioned in this section. Contents on the LHRDs have to be distributed wisely so that user can experience benefits of large space more efficiently. Furthermore, content management determines the way of accessing the content on a display. Therefore document navigation is something to be considered together with content management.

Gutwin et al. [GCG+17] investigated how spatially-stable overview effects user experience and performance. They designed a PDF reader in order to evaluate the performance of different navigation methods such as scrolling, overview, and scrolling+thumbnails. Due to the spatial memory, experiments in this study show that overview method has the best performance, especially in some specific cases. Robertson et al. [RCL+98] made another research related to benefits of spatial memory. They proposed a new technique for document management called *Data Mountain* which allows users to place thumbnails in a virtual 3D environment. According to the user study in which *Data Mountain* is used to manage bookmarks, *Data Mountain* has more advantages in comparison to standard Microsoft Internet Explorer Favourite mechanism. In order to compare the performance of the *Data Mountain* metrics such as reaction time, incorrect retrievals,

failed attempts are used. Cockburn et al. [CKB08] investigated four document navigation approaches overview+detail, zooming, focus+context and cue-based techniques. Hornbak and Frokjar [HF01] examined the usability of different types of interfaces for electronic documents empirically. Linear, fisheye, and overview+detail interfaces are compared, and as a conclusion, overview+detail interfaces are recommended. Baudisch, N. Good [Bau01] designed an interface with a focus+context approach by combining low and high-resolution displays. Focus area is displayed on high-resolution displays while context area is depicted on a lower resolution display.

Several studies examined how to develop novel window manager systems. Chapuis and Roussel [CR05] developed the tool, *Metisse* to allow designers to create new window management systems easily. Although conventional window managers cover only certain types of desktop set-ups, non-standard displays are commonly used in workspaces. Therefore Waldner et al. [WGSS11] introduced a novel technique to manage windows for the displays with different shapes and sizes. According to the conducted user study, it is observed that users tend to create a close focus and a distant context area. Besides several text visualisation techniques, aiming better comprehension by users, are presented below. Hutchings et al. [HSM+04] examined user behaviour on different monitor set-ups by logging windows management activity in order to compare single, multiple and large multiple monitor users. Through this research important results have been obtained which can be used to design more efficient windows managers for large displays. Bi et al. [BBB14] made a similar research with the main focus of LHRDs which proposes *WallTop* as a window management tool optimized for large displays. Some new interaction techniques to arrange windows are also integrated into *WallTop*. In order to improve copy-paste performance on partially overlapping windows, Chapuis and Roussel [CR07] propose two methods, *restack* and *roll*. According to the experiment results with *restack* and *roll* methods, users perform significantly better with four different copy-paste techniques, using a keyboard, menus, drag-and-drop; and X Window.

Uddin et al. [UGC17] evaluated the effects of adding artificial visual guides such as transparent image and anchor points to a grid menu. As a result of the experimental study measuring completion times of certain tasks, they recorded a significant performance improvement with anchor marks for medium and large-sized grid menus. Avellino et al. [AMB+17] present a platform, *CamRay* to support collaborative work on LHRDs by adding telepresence feature with the help of an embedded video feed in shared documents. They investigated through an experiment how the position and movement behaviour of the video feed in the content affects user performance. Regarding layout management, Maudet et al. [MTB+17] created two tools, *Contextify* and *Linkify* to support graphical designers in their process of structuring layouts. According to the study, designers use more complex layouts than grids which are called *graphical substrates* in this context. *Contextify* allows designers to create dynamic layouts subject to users' preferences while *Linkify* helps to design content dependent dynamic layouts.

Visualisation of text documents provides an environment, in which users can comprehend the content and perform their tasks more efficiently. Koch et al. [KJW+14] introduced *VarifocalReader*, a visual analysis tool for large text documents, which combines both overview+detail and focus+context approaches to bring their advantages together. Dou et al. [DYW+13] announced another visual analytic tool, *HierarchicalTopics* which enables large texts to be visually explored by making use of the hierarchical topic structure.

From the studies as mentioned earlier, we deduced that spatial memory has to be considered for content management design. We figured out the challenges of window management on different displays with extraordinary size and shapes. Furthermore, it can be seen that with overview+detail interfaces, it is possible to achieve more efficient document navigation on LHRDs than the other alternatives. Finally, the latter researches provide insight into additional visual support for large text documents.

## 2.2 Cognitive Effects

Size, resolution and interaction techniques of LHRDs have different impacts on cognitive abilities of users. Andrews et al. [AEN10] investigated how sensemaking is supported by increased spatial availability of LHRDs. O'Hara et al. [OSB99] examined the effect of spatial memory during the reading process with various interface techniques. Assumptions are examined through an experiment with two set-ups *focus+context* and *the scrolling interface*, where the first one provides a static overview, and the latter has a dynamic context view. The study concluded that despite the scrolling interface, the *focus+context* interface supports reader to retrieve information relying on spatial memory. A study of Czerwinski et al. [CTR02] inquires how large displays can support women which are proposed to outperform in virtual navigation environments. The study shows that gender bias in 3D navigation can be reduced by increasing field of view. Another study of Czerwinski et al. [CSR+03] demonstrated through a *satisfaction survey* that large displays have better user satisfaction measures over small displays. Yost et al. [YHN07] explored the impact of scaled-up visualisation that exceeds visual acuity in terms of performance and perceptual scalability. The experiment made by using LHRDs shows that despite the physical navigation needed, visual acuity is not a limiting factor to scale up visualisation. The effects of physical discontinuities such as bezels in multiple monitor set-ups are investigated by Tan and Czerwinski [TC03]. As a result of the user study, they concluded that physical discontinuities has no effect on performance. On the other hand, there also exists another research by Wallace et al. [WVL14] which unveils that thinner bezels may have a positive effect for searching tasks. Bradel et al. [BEK+13] made a research to examine how users develop territories in a collaborative work using

LHRDs. The study made an experiment in order to compare different distributions of workspace among collaborating users and concluded that users with more shared space usage are more successful in their tasks.

All these studies inspire my thesis by supporting the fact that LHRDs lead to various cognitive benefits such as more user satisfaction and manipulation of spatial memory. It is also a source of motivation that LHRDs can reduce gender bias in workspaces. Moreover, some researches provide us important information about the cognitive effect of discontinuities for the design phase of the project.

### 2.3 Interaction

As interaction techniques for LHRDs are not standardized yet, it is an important part of this thesis to clarify how users interact with the PDF reader. There are already some studies in the literature that point out the interaction issues in my thesis. Several novel interaction techniques, as well as modified mouse-keyboard and conventional touch panel interactions are introduced in this section.

Ball et al. [BSN06] proposed that by using cursors with dynamic size and speed in LHRDs, performance can be increased. This proposal is also supported by a set of experiments which show high-speed cursors has a better performance over the standard cursor. They also unveiled gender bias in simple drag and drop operations which however disappears in more complex tasks. Some interaction techniques called *ZoomScape* and *Typed Drag and Drop* for wall size displays are described by Guimbretière et al. [GSW01] in order to achieve their design goals. These aims are high resolution, clean screen, fluid interaction and shaped by being wall-like property of such displays. The fluid interaction describes here a simple uninterrupted GUI unlikely to standards ones without complex distracting features such as dialog boxes. Liu et al. [LCBL17] introduce a new multi-touch interaction method called *CoReach* in order to facilitate collaborative work on wall-sized displays. Another novel interaction technique, *Shadow Reaching* is proposed for large displays by Shoemaker et al. [STB07]. The study suggests using user's perspective-projected physical shadow with the help of a light source on large-displays as input modality due to its many advantages.

Several researches propose using smaller screens as an input method for controlling a content of large displays. Malik et al. [MRB05] developed several new interaction techniques with recognition of gestures similar to those which are used in touch-pads. For this purpose a large-display is mapped onto a touch pad which is traced by a camera to recognize gestures. Lischke et al. [LHK+17] examined interaction methods for data-intensive tasks such as twitter datasets on LHRDs and presented a technique that allows



multiple users to interact with several tablets. In comparison to desktop interface, tablet interface achieves better user satisfaction and performance according to the experiment results. Chapuis et al. [CBF14] presented Smarties, a mobile touch-screen that provides a multi-user wireless interface for LHRDs. They developed the library as server-client based where widgets are available to users and communication protocol is hidden.

Ahlborn et al. [ATK+05] investigated implementation details of laser pointer interaction to be used for large displays. The dot on display has to be detected by a camera, and therefore a recognition algorithm is also presented in this study. The laser dot basically replaces the cursor in standard mouse interaction technique. Peck et al. [PNB09] proposed a multi-scale interaction technique which uses user's position to change the scale of interaction. Unlikely to conventional methods like mouse and keyboard, this solution encourages user to benefit physical navigation. A user study which is conducted to show impacts of this method shows that changing interaction scale subject to users' position is natural to people however there are also some disadvantages. As an aid to standard mouse and keyboard utilisation for window management tasks on LHRD, Lischke et al. [LKK15] suggest using mid-air gestures. Lischke et al. [LSF+16] examined the usability of *MAGIC-Pointing* on LHRDs which uses eye gaze tracing as an input modality. The results of their user study indicated that TCT is significantly reduced by using *MAGIC-Pointing*.

As a result of this literature research, the term *fluid interaction* appears as an important aspect in the design phase of GUI. After evaluation of different interaction methods mentioned above, we decided to use wireless mouse and keyboard with a touchpad in order to keep it as simple as possible to focus more on the other features of the PDF reader.

## 2.4 Large Display Workspaces

Overall physical design of LHRDs has impacts on users experience. There are some researches on this topic which motivate us to develop a useful set-up for this thesis. By changing design characteristics of a workspace with LHRD, Endert et al. [EBZ+12] investigate different impacts of the physical structure. While some adjustments such as height and curvature of the display are specific to the output device, different configurations of input devices namely mouse and keyboard placement are considered as well. Huang et al. [HMRS06] evaluated various workspaces with large displays for collaborative work and made a guideline for group-ware workspace development. Yang et al. [YCNF10] developed a prototype workspace to show electronic documents on LHRDs for performance comparison with other display methods. Johanson et al. [JFW02] developed an interactive workspace prototype called *iRoom* which allows group

meetings in an interactive room, and implemented corresponding software, *iROS* that is required for GUI and interactions. Lischke et al. [LMW+16] conducted a user-centred design study in order to make a user-friendly screen arrangement for large display workspaces. Participants in the study were allowed to change screen arrangements as well as the window management according to various scenarios. Social effects of using large display workspaces in collaborative works are examined as well [RDS02]. Novak et al. [NAS08] suggested a commercial use of interactive large-display workspaces with touch screen for travel consultancies. Success potential of this idea is evaluated in a real-world experiment with twelve customers and four travel agency. The trade-off between group-ware and individual requirements for designing a workspace is tackled by a research [GG98]. Jakobsen and Hornbaek [JH14] investigated user behaviours during a collaborative work in group-ware workspaces with multi-touch large displays.

Challenges in design of large workspaces are reviewed through preceding studies. We obtained the knowledge of how changing adjustments of LHRDs in size and shape affects user experience and performance. Additionally, configuration of input devices, which is previously investigated, is also something that we need to develop an LHRD PDF reader. Regarding the collaborative usage of our prototype as well, we benefit from aforementioned works.

### 2.5 Methodology

For the design workshop to be conducted for this thesis, there are already several researches that influence us to elicit design ideas from the participants. Halskov and Dalsgård [HD06] initially proposed *inspiration card workshops* where printed cardboard cards are used to represent either an application or information. According to this approach, participants of design workshops are able to express their design ideas collectively by combining cards on a poster. Another comparable method to design user interfaces is paper prototyping. Bailey et al. [BBCM08] extended this method for multiple display environments and proposed a number of recommendations which are quite useful for our works. Additionally, another concept for the user study in this thesis is using whiteboards by analogy with LHRDs. Regarding whiteboard utilization Branham et al. [BGC10] introduced *ReBoard*, a tool that brings reusability and sharing feature to the whiteboards in order to examine their capabilities. Similarly Walny et al. [WCR+11] examined whiteboards thoroughly by analysing visual constructs of 69 participants. Asserting that users need to have a previous experience similar to novel interfaces for faster adaptation, Tang et al. [TLGF09] examined user behaviour on whiteboards to develop large display applications. Combining paper prototyping with whiteboards, Knudsen et al. [KJH12] conducted a workshop to create new ideas

for LHRD interaction techniques. Various tasks are performed by the participants from different fields using whiteboards and printed papers. After analysing visual outputs in the workshops, Knudsen et al. [KJH12] presented a number of design ideas. This study can be considered as the most influencing work that provides a guidance us to develop a workshop for GUI design.

## 2.6 Influences of LHRDs on Performance

In the literature, there are numerous works that investigate how usage of LHRDs brings about performance increase for certain tasks. For instance, Tan et al. [TGSP03] show in an experimental study how performance in spatial tasks is improved while for reading comprehension task there is no significant performance change. For this research, they kept visual angle constant by increasing distance to the display as screen size is increased. Through a user study comparing 15-inch flat panel display with 42-inch wide surface Czerwinski et al. [CSR+03] shows that increase in display size boosts users' productivity for cognitively loaded tasks. In their experimental study Ball and North [BN05] observed that performance is increased with a LHRD for the tasks where task switching or supportive information are needed. They concluded that less virtual navigation and less need of switching lead to this performance increase. Ball et al. [BNB07] further examined performance display size relationship connected with the amount of physical and virtual navigation. Ni et al. [NBC06] made a controlled experiment that shows display size and resolution in an Information-Rich Virtual Environment (IRVE), which is defined as "a realistic virtual environment that is enhanced with the addition of related abstract information [BNC+03]", increase performance in completing search, comparison and navigation tasks. Narrowing the focus of performance studies, Liu et al. [LCB+14] examined impacts of display size on performance in performing data manipulation tasks, which are excluded in previous works. Experiments in this study demonstrate that display size increases performance only for complex and data-intensive tasks. Lischke et al. [LMW+15] investigated impacts of display size by changing the width of LHRDs in a controlled experiment. While other related works compare large displays with only standard small displays, this study examined what kind of behaviour user performance shows when the width of an LHRD set-up changes. Results of the experiment show that relationship between display size and performance is not linear.

Previous works above demonstrate that LHRDs cause performance improvement in some cases that have intersection points with this thesis. Through these related works it can be seen also that performance improvement depends on not only display size but also data intensity and navigation techniques. The last work above gives an idea about how big enough the display has to be and which size would be optimal. Besides performance

improvement with the usage of LHRDs is another source of motivation for the thesis to build an efficient PDF reader.

## 3 GUI Design Elicitation Study

In order to elicit design concepts to develop a GUI for PDF documents on LHRDs, we conducted a design workshop with twelve participants. The purpose is to evaluate following aspects of the GUI of our prototype: layout configuration, windows management on multiple screens, multiple file interactions. Participants are selected from academia who have experience with reading scientific articles by using a standard PDF reader.

### 3.1 Methodology

As proposed by Knudsen et al. [KJH12], we used paper prototyping along with a whiteboard that represents an LHRD (Figure 3.1). This method is designed to observe how professionals do data analysis tasks on wall-sized displays in a real word environment. The approach requires participants to imagine the whiteboard as an LHRD. Knudsen et al. [KJH12] argue that generalizability and being based on a concrete data set are the benefits of the method.

#### 3.1.1 Demographics

In this thesis, we chose to work with the academic staff since it was the easiest profession group to find at the university. We recruited twelve people, eight male, four female (see Table 3.1) by word-of-mouth advertising. The average age of participants whose ages vary between 22 and 44 is 31. They consist of researchers who represent different institutes and disciplines as follows: Institute for Visualization and Interactive Systems (VIS), Institute of Applied Mechanics, Institute for Modelling Hydraulic and Environmental Systems, Media Informatics, Institute of Railway and Transportation Engineering, Institute of Organic Chemistry. They participated voluntarily and we compensated their efforts with sweets and chocolates after the workshop.

Participant ID	Age	Gender	Institute
1	27	male	Visualization and Interactive Systeme (VIS)
2	34	male	Visualization and Interactive Systeme (VIS)
3	22	female	Visualization and Interactive Systeme (VIS)
4	32	male	Visualization and Interactive Systeme (VIS)
5	27	female	Visualization and Interactive Systeme (VIS)
6	29	male	Visualization and Interactive Systeme (VIS)
7	26	female	Institute of Applied Mechanics
8	30	male	Institute for Modelling Hydraulic and Environmental Systems(IWS)
9	32	male	Institute for Modelling Hydraulic and Environmental Systems(IWS)
10	41	female	Media Informatics
11	44	male	Institute of Railway and Transportation Engineering
12	27	male	Institute of Organic Chemistry

**Table 3.1:** Participants' profile in the design workshops

#### 3.1.2 Data Set

We decided to utilize scientific articles as the data set since they are part of the ordinary working life of academic researchers. Hence, we requested participants to send us three papers related to their area of interests before the study. We printed them in three different sizes, A3, A4 and A5. One related work was randomly extracted from each paper, and printed in the same three dimensions as well. There was no restriction with the page sizes. However, there was a limitation of document type. Only scientific article type documents were allowed but not books. The number of pages of the papers we received vary between 1 to 20 pages.

#### 3.1.3 Conducting the Workshops

The workshop starts with introducing tasks and materials. This includes signing the consent form as a proof of an ethical agreement and filling demographics form as well. We distributed papers in three different sizes, A3, A4 and A5 to simulate PDF content. Participants were told to place the papers on the whiteboard as they wish to demonstrate the usage the display space. This was done with the help of magnets that allow movements of the papers easily. These movements correspond to drag/drop operation in the real interface. Other attributes related to GUI can be depicted with

whiteboard markers in different colours. Participants were not restricted to a specific type of interaction method. If the result of a task already referred to its next tasks, we did not repeat it again. All activities of the participants were recorded by a video camera to be analysed later.



**Figure 3.1:** General view of the set-up during a workshop

The design study consists of three tasks about using display space assuming that user reads papers, reviews papers or make a literature review. We initially assigned approximately ten minutes for each task and 15 minutes for the interview. In order to learn participants' opinions about the design study and generally about the topic, we posed following questions at the end; "What challenges did you face during experiment?", "Did you have difficulties associating whiteboard to an LHRD?", "Did you have difficulties associating printed papers to real documents?", "Which aspects of the idea of using a PDF reader on LHRDs did you like/dislike?", "For which case a PDF reader on LHRDs do you find most useful?".

## 3.2 Analysis of Results

This section comprises presentation and interpretation of the design workshop results. We investigate here common properties and diversities of the user behaviours

regarding layout of the content, overview preferences, management of multiple documents, navigation type, auxiliary windows and annotations for meta-information (Table 3.2).

Participant ID	Notes	Browser	Text Editor	Diff. Sized Papers	Movable Pages	Meta-info
1	X			X		
2	X		X	X		
3	X				X	
4	X	X	X	X		
5		X		X		X
6	X	X		X	X	
7	X	X		X	X	
8				X	X	X
9	X			X		
10	X			X		
11	X	X	X			
12	X			X		X

**Table 3.2:** Extraction of design study results.

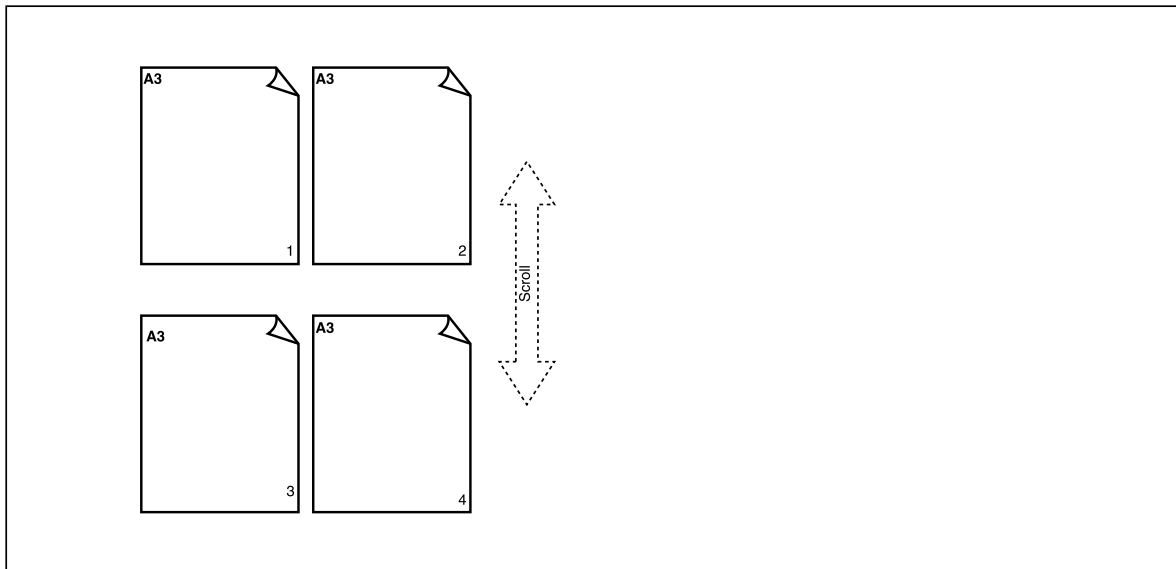
#### 3.2.1 Navigation Types

Ten of the participants preferred spatial navigation for switching between different pages of the paper. As distinct from the others, one participant chose to use scroll button for browsing pages to avoid physical activity for the first task (Figure 3.2).

*I don't like large spaces so I would stick them like in the books. I would put another set if I would like to check multiple papers side by side, very close to each other. But If I read just one paper then I would like to see the paper like that. I would scroll down to see the rest of the paper because I don't have a large screen like this, this is what I would do. [Participant 7]*

However, she changed this preference for the next tasks where the need for space to show information increased. The other exception was the user who demanded a tabbed screen due to the lack of display space as a result of his paper big size selection. Because of his visual impairment, he maximized the paper size even larger than the largest paper size that we provided. He depicted an imaginary boundary for the paper with the markers.





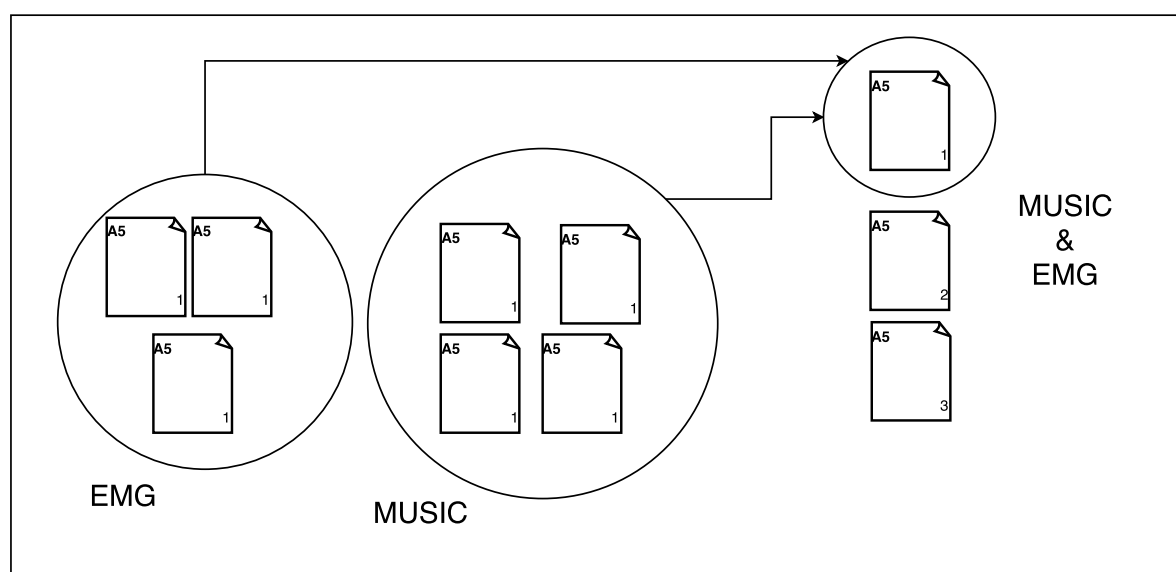
**Figure 3.2:** Scroll button interface

### 3.2.2 Layout of the Pages

Eleven of the workshop participants started using horizontal tiling for each single documents for reading and reviewing tasks when there is enough space. Whenever the first line is full, they switched to next line to arrange pages. Only one participant started the first task using grid tile. In the presence of multiple documents at the same time, they placed each document top and bottom but horizontally in itself. With more than half of the users, we observed also aggregated pages especially for the literature search task where only one or several pages are visible (Figure 3.3).

*I would like to use small pages for related work, the first page, because the abstract is important to see if they are really related, so I can copy 5-6 related work in this large empty space. I would combine the papers and relate them to categories.* [Participant 1]

Although pages of a document are normally placed quite close to each other, four participants changed this structure to obtain more space to take notes particularly for reviewing a paper. The rest used available lateral areas or below the pages. Two participants overlapped some pages of related work and references respectively onto the main paper.



**Figure 3.3:** Aggregated view of related works

### 3.2.3 Overview Preferences

Most of the participants used document itself as an overview. On the other hand, one user suggested an additional overview in a smaller size on top of the screen (Figure 3.4). Another unique approach was displaying only figures, first and last pages at the beginning before deciding to read the entire document. Seven participants used first pages of papers mainly in smallest size, which include only title and abstract, to give an overview of related work. One user viewed the related work normally in the smallest size and imagined a magnifier to focus on the parts in which he is more interested.

Four participants chose to draw arrows to organize related works and make connections between them. One of those participants used arrows to connect different sets of related works as depicted in Figure 3.3. Another approach that connects linked relationships between related works is proposed by two participants as shown in Figure 3.5.

*I would select a reference then open it in a new window, then the other, I need to track all of these. But this one is limited because there is no much space, because I need lots of references. [Participant 3]*

Another participant chose to arrange related works in the form of a tree with the arrow marks.

There was one participant who separated focus and overview areas for the literature research as depicted in Figure 3.6.

Two researchers indicated their discipline-specific requirements. The nomenclature section is displayed as an overview by one researcher for the papers which have a high intensity of mathematical notations as shown in Figure 3.4. A different user expressed that he would use an overview of the *Supporting Information* which is frequently used in the field of applied chemistry.

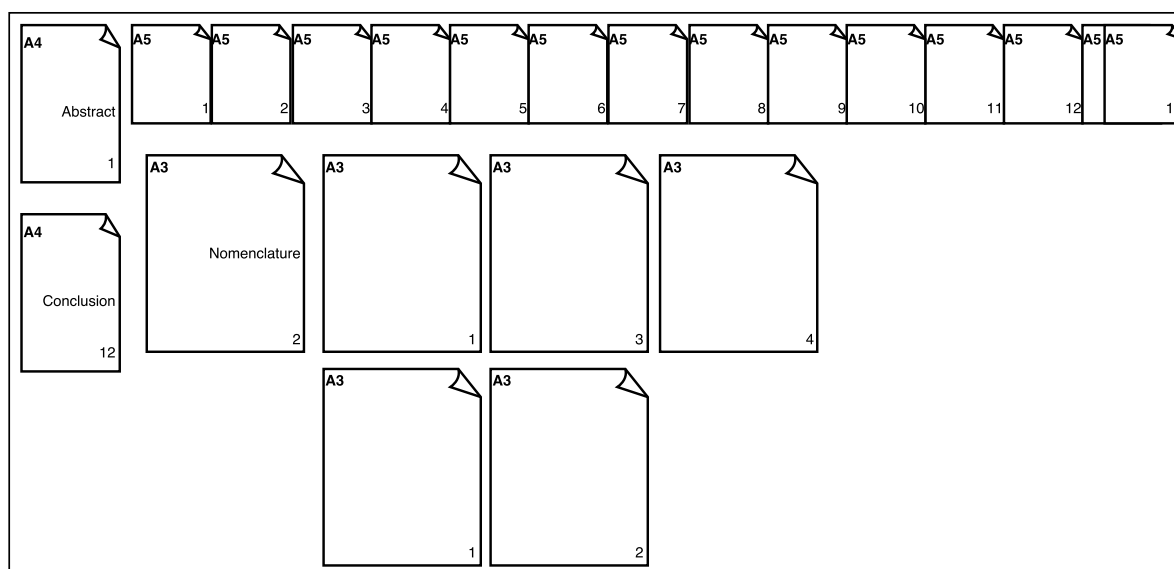


Figure 3.4: Additional overview on the top

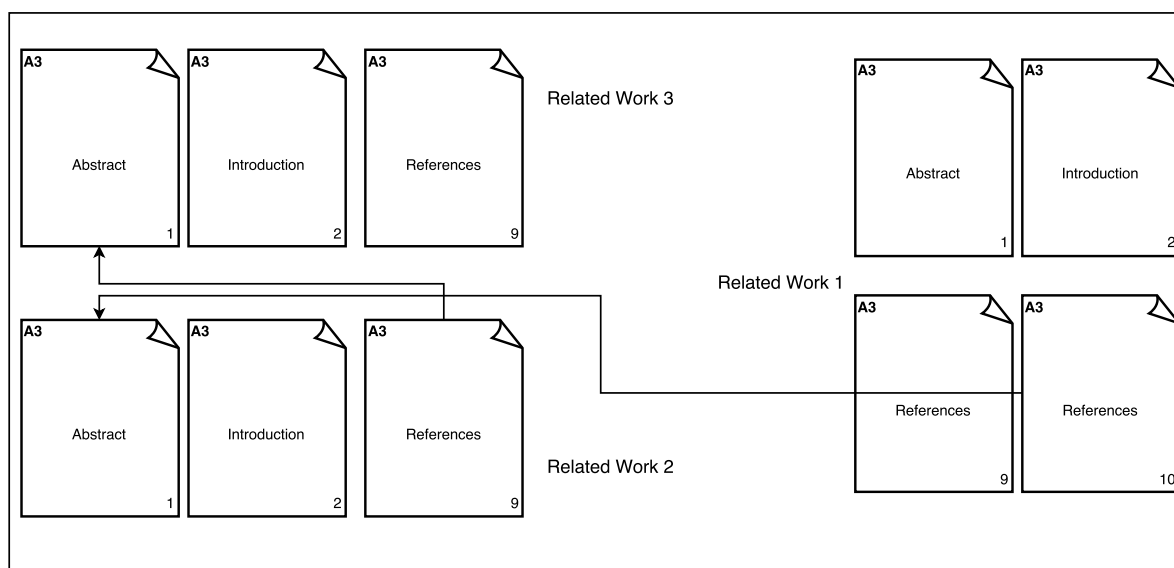
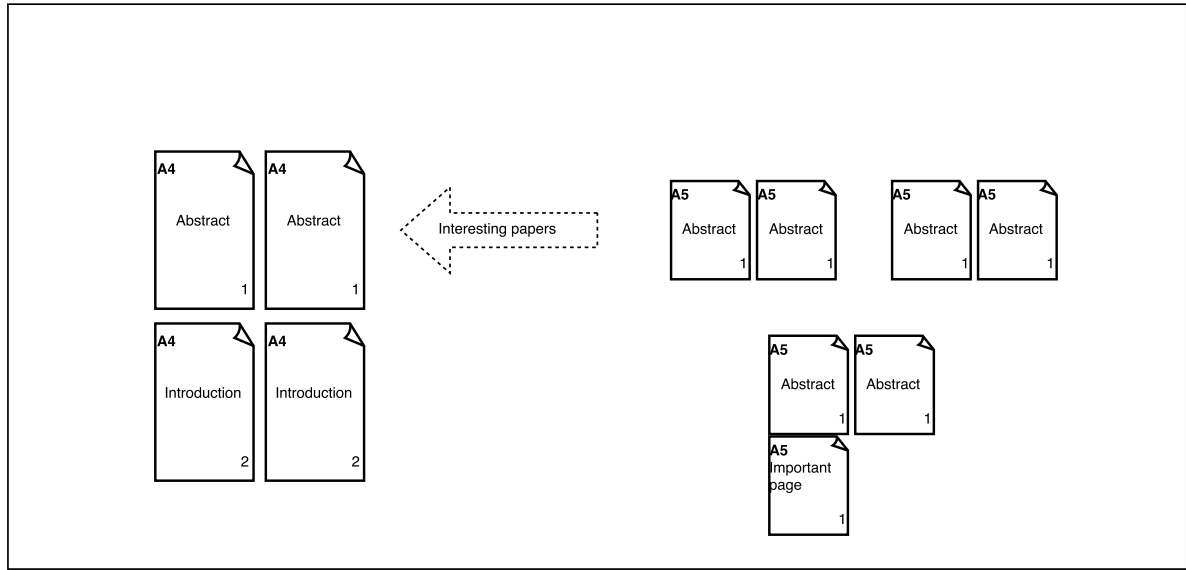


Figure 3.5: Linked relationship between related works



**Figure 3.6:** Focus and overview areas

#### 3.2.4 Auxiliary Windows and Meta-information

Ten of the participants needed some place to take notes particularly for reviewing task while three of them explicitly referred this as a text editor as can be seen in Figure 3.7.

*When I would like to quote from pages, I would like to have a note place for each pages then I would need a summary note page to summarize all notes.*  
[Participant 2]

As depicted in Figure 3.8, five participants added a built-in browser for literature research task. One user suggested a pop-up window to show reference instead of visiting the last page and one window for a translator to read articles in a foreign language.

As an overall evaluation for the reviewing task, one of the participants depicted a smiley to indicate a satisfaction. Another one suggested a success scale from to give a grade for the reviewed paper.

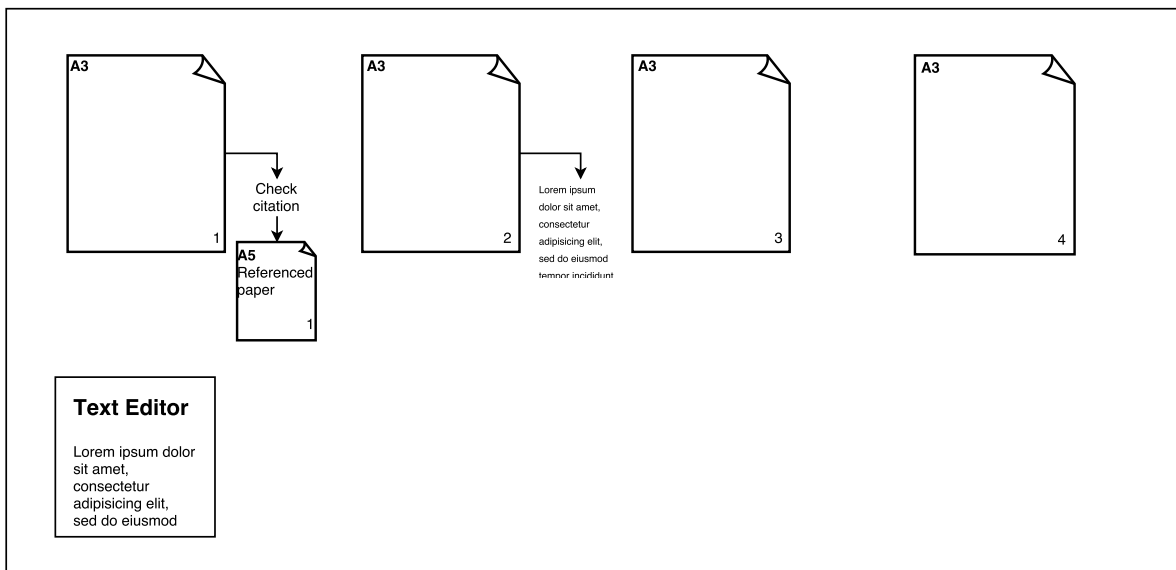
Due to the available space on the display, three users wanted to highlight some meta-information of the papers such as citation rate, publication dates and information about authors (Figure 3.9).

*Sometimes I would like to search authors. I would look to citation rate of the paper; and then who is publishing something similar, so I would like to have at the top of the screen that gives automatically.* [Participant 5]

One person imagined to have an intelligent assistance software to simplify or correct complex expressions in the paper.

*Let's say this sentence is written not correctly or I did not understand. If there is a feature that would simplify, would be great. [Participant 5]*

As can be seen in Figure 3.9, a search functionality is also desired by the participant to find occurrences of a keyword through all the open documents.



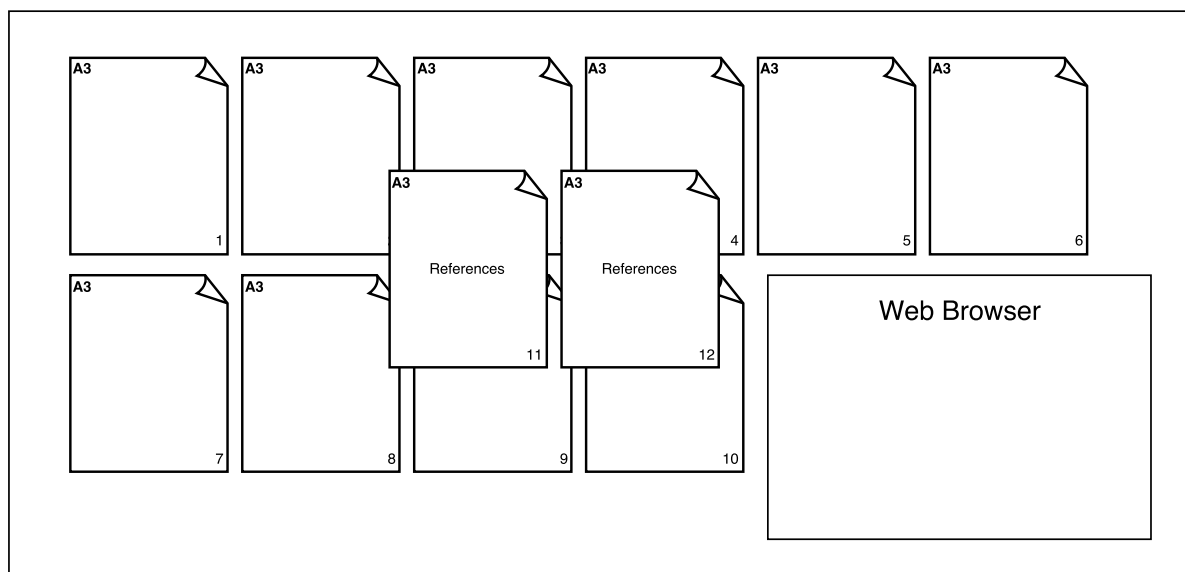
**Figure 3.7:** Text editor

### 3.2.5 Content Mobility

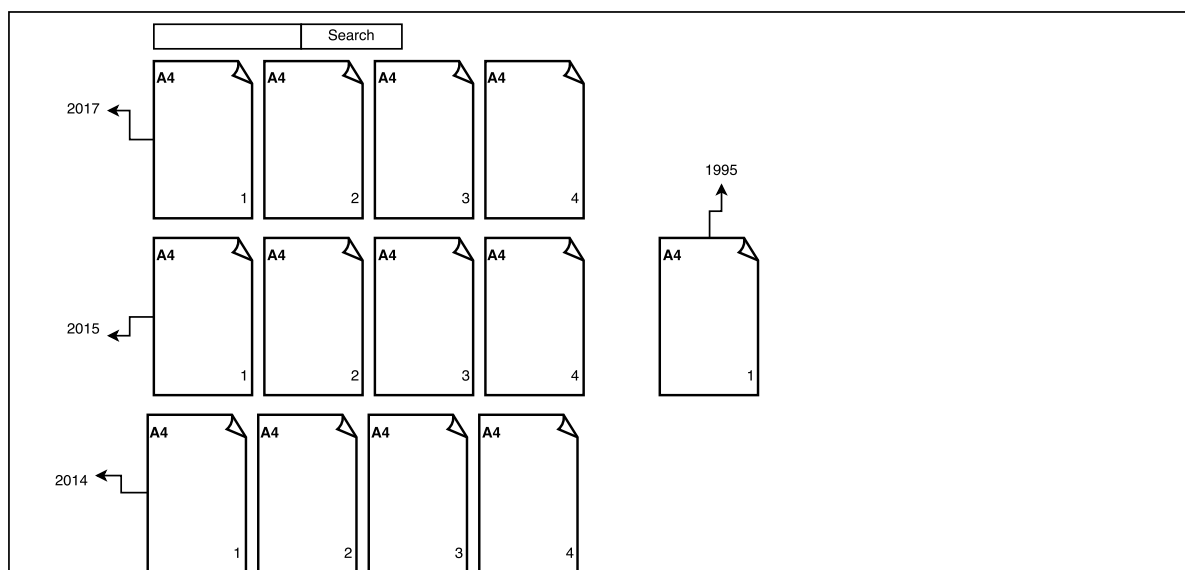
One aspect that we observed during the design workshops is the change in the size of the pages. Ten users chose to use different sized papers which represents zooming feature in a real environment. Additionally, two participants explicitly expressed the importance of zooming.

Four participants imagined that papers of the documents could move freely and independently. As shown in Figure 3.10, one of these interactions is to remove an uninteresting page then shifting the other pages to fill the gap.

*When a page is unnecessary, I would like to remove it from the screen. [Participant 3]*



**Figure 3.8:** Built-in browser

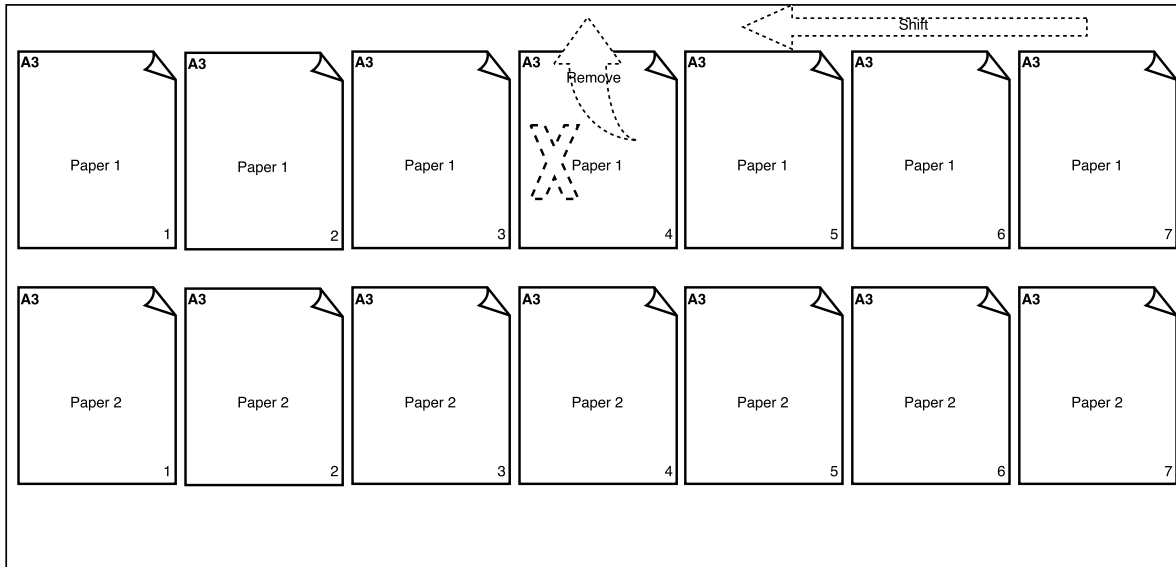


**Figure 3.9:** Annotations for the publication date

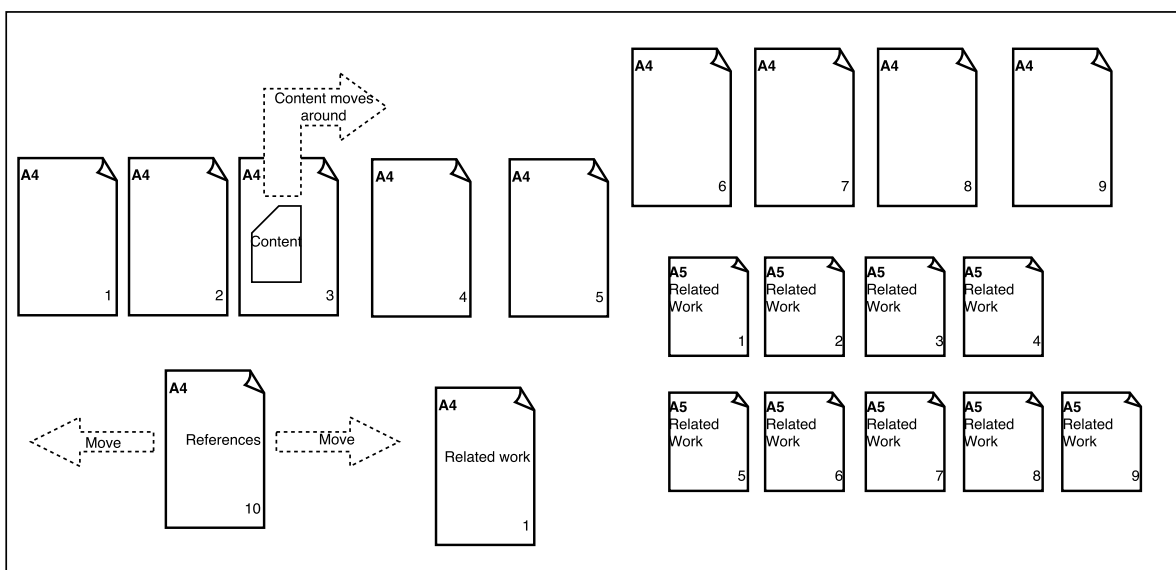
As can be seen in Figure 3.11, another related interaction is to move references along with the other pages of the document.

*Something that I am doing when I read related works, I put references close to related works that I need and move it where I go through the paper. [Participant 6]*

The mobility of pages is imagined by one person for grouping interesting related work after skimming.



**Figure 3.10:** Removing an irrelevant page



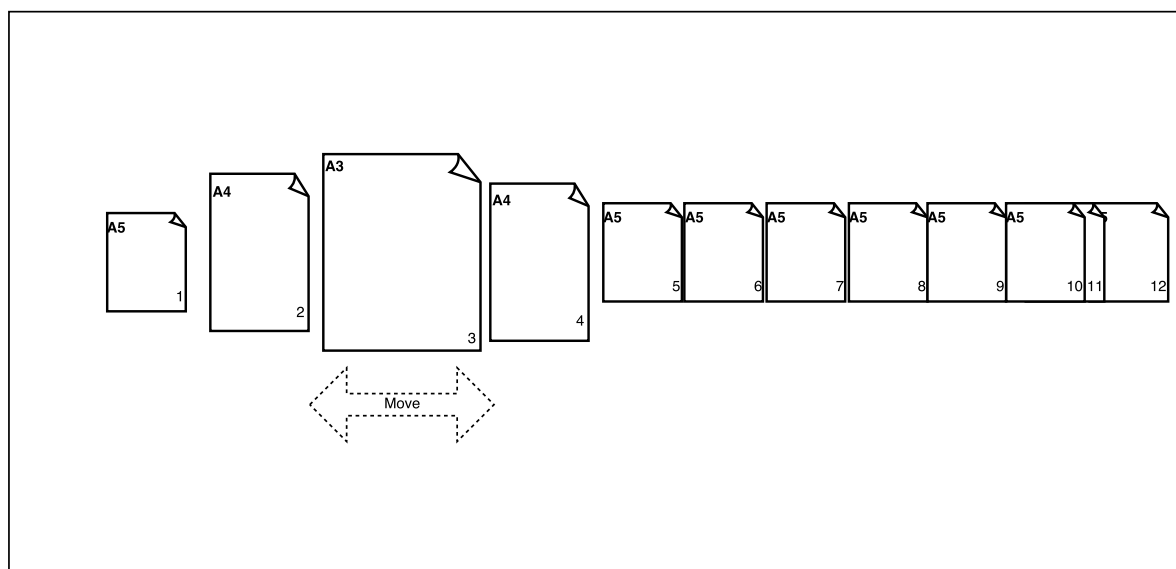
**Figure 3.11:** Movable references page

One participant expressed that focused page should be zoomed in by the move of reader interactively as depicted in Figure 3.12. She further emphasized the importance of interactivity for her to compensate the physical activity. A different participant described one more interactive interface regarding body movement detection.

*If I am approaching one of the images, the text has to appear around this figure. It would be great if this display detects automatically that I am approaching this figure or looking at this figure so that I can see what is relevant. [Participant 4]*

Another interesting idea was to move content out of the document to compare easier with the content on another page.

*If I would be able to take a part of paper move it to a place where it is referenced by so I would not have to go back again and again. [Participant 6]*



**Figure 3.12:** Interactive interaction with the content

#### 3.2.6 Interview

We analysed the output of interview part of this design study regarding five questions below.

What challenges did you face during the experiment?

Three of twelve participants stated that they did not face any challenges during the experiment. However, we received also a number of feedbacks about the difficulties in this design study. Four participants commented that changing usual way of thinking to



arrange documents was a challenging task, since it was different set-up from what they usually use to view documents.

*At the beginning, It was difficult for me to get out of my usual way of thinking in terms of how I use my monitor, what would I change? But that was it.*  
[Participant 7]

One person mentioned that it was difficult to decide where to stand while interacting with such a large display. Another participant claimed that it was hard to simulate animations with the set-up which is used in the study. According to one person, displaying huge amount data was one of the challenges. One participant commented that the lack of zooming functionality and having a limited number of printed papers is a deficiency of the design workshop methodology.

Did you have difficulties associating whiteboard to an LHRD?

The half of the participants expressed that they did not have any difficulties associating whiteboard to an LHRD. On the other hand, three of them had difficulties due to the lack of information of functionality in a real set-up, since they have never used such a display.

*A little bit because, I guess, the display would have some more functionalities than just the whiteboard did. So I am not really sure what exactly would the display do. Because I have not worked with such displays; at the moment it might be just touch-screen but it could be something different in the future.*  
[Participant 3]

One participant indicated that it was hard to associate zooming functionality with whiteboard prototyping. Another one reported that despite the fact that he has already used an LHRD before, he was not sure about how his imagination would change after using it for a while.

Did you have difficulties associating printed papers to real documents?

None of the participants had difficulties associating printed papers to real documents according to the interview results. Moreover, two participants emphasized that they normally prefer to read documents in printed form; therefore they feel more comfortable with it.

Which aspects of the idea of using a PDF reader on LHRDs did you like/dislike?

The half of the participants pointed to the advantage of seeing the entire document on one page due to the available large space. Three of out those six people reported that it is important for them to have less tab switching and scrolling.

*What I like is that there is really large area that provides plenty of context so that I don't need to switch all time which is annoying. On the down side, it is so large that I have to move. Large screens could get uncomfortable if you are there more than 4-5 hours. [Participant 4]*

The other three emphasized the benefit of having an overview feature. On the other hand, the three participants indicated that the activity required for physical navigation might be exhausting and one person suggested using a chair and desk. To be able to have a larger font size without compromising visibility was liked only by one person. The two participants stated the importance of interactivity such as related work that appears automatically, showing videos of the paper. One participant mentioned the ability of sorting and grouping documents as well as saving and loading workspaces as an advantage. According to two participants, the attractiveness of using a PDF reader on an LHRDs depends on its affordability. They found it worth to use if it is not too costly. One participant stated that it would be especially useful for collaborative work but not efficient just to focus on one page.

For which case a PDF reader on LHRDs do you find most useful?

Only two participants replied to this question with an answer that using a PDF reader on LHRDs is useful for reading documents. One of their reasons was the ability to see the entire document on one screen while the other one was to ease collaborative reading. According to eight participants, this kind of PDF reader would be particularly useful for the literature research task. The one argument for this kind of answer is the ability to use different tools. Another participant stated that the reason was the number of documents. We also received two similar comments related to this answer that organizing big amount of related works is easier with this set-up.

*For especially the last one (literature research) because a typical paper in my area if it is a research paper, has fifty citations [...], and I think it helps to use this display for sorting and organizing them. [Participant 8]*

One of the participants explicitly indicated that she already uses larger displays while she is doing literature research. Five participants found the set-up useful for reviewing task alone or together with some other tasks.

*For certain task like reviewing it is good thing to have whole thing that you can go back to one part easily instead of scrolling through whole thing. [Participant 7]*

One of the researchers expressed that it is useless for all three tasks at all. Another person answered the question that it is useful for none of those three tasks at all.



## 4 Implementation

After analysis of the workshop results, we started implementing a working prototype as a PDF reader. We aimed to develop an interface satisfying overall expectations of the workshop participants. We enabled to handle different pages of a document separately to allow users to create their personal spaces freely (see Figure 4.2). With the flexible interface that we provided, it is possible to realize most of the concepts which were described in the design workshops. We accomplished to provide supporting tools which are mentioned by the participants such as built-in text editor (Figure 4.4), web browser (Figure 4.5), and search functionality (Figure 4.6). Moreover, we offer the feature of saving and loading sessions. This chapter describes design considerations and development tools used in the implementation part.

### 4.1 Development Tools

PDF is a platform-independent file format to display electronic documents [Inc06; TPZM04]. A PDF file stores all the important information about the document such as text, font, images, and layout. A renderer is required to interpret this format and display a PDF document which is based on a simplified page description programming language. Therefore, our first step was to find an appropriate open source PDF renderer. After evaluation of a number of alternatives, we decided to use MuPDF<sup>1</sup> software since it provides a fast, lightweight renderer with high-quality anti-aliased graphics. It makes possible to open and handle a large number of documents with high resolutions simultaneously. Since it is written in C, it also conforms to our plan to implement the prototype using C/C++ programming language. We used the latest stable version (1.10a) under the GNU Affero General Public License (AGPL).

In order to realize the GUI for the prototype, we created a *Qt Widgets Application* using *Qt Creator* as an IDE. Qt<sup>2</sup> provides an extensive library to develop native C/C++ applications under GPL & LGPLv3 licenses. With the help of its signals and slots interface,

---

<sup>1</sup><https://www.mupdf.com>

<sup>2</sup><https://www.qt.io>

different objects can communicate with each other in a reliable way. Furthermore, it offers a number of classes that can be alternative to C++ standard library since it is more compatible with the rest of the Qt library.

Qt Creator is completely compatible with Qt library and it is also possible to configure external tool-chains. It is equipped with a design interface which enables visually arranging window forms which are stored as Extensible Markup Language (XML) files with .ui extension.

The library file generated by the MuPDF project is linked statically to our *Qt Widgets Application*, so that is possible to use functions of the renderer as APIs. MuPDF source files come with a Visual Studio Project files thus it was easy to compile with a proper configuration to generate static library files. We used 32-bit Visual C++ 2015 compiler<sup>3</sup> to compile both the MuPDF library and our Qt project.

Qt comes with a tool called *qmake* which is needed to generate makefiles for the compilation. As an input, it takes a project file (.pro) which defines project configuration. Static linking of dependency libraries is made in this project file. In addition to the MuPDF library file (libmupdf.lib), libraries for the fonts (libfonts.lib) and for the third party software (libthirdparty.lib) are linked as well. All the necessary functions of the PDF renderer are declared in a header file called "fitz.h". It has to be included in our source code to be able to use the library functions thus the file path of all the dependent header files are added to include path of the project.

Qt libraries used in the project have to be linked dynamically. For this reason, after compilation of the project and getting the output file relevant .dll files need to be copied to the same directory with the output executable. This can be done automatically by using Windows deployment tool of Qt (windeployqt). It takes output executable function as an input. Dependency files can also be traced with a free software called *Dependency Walker*<sup>4</sup>.

### 4.2 Core Functionality

Initially, a *Document* object created for each PDF document. Displaying a PDF document starts with opening the file by calling an API of MuPDF which takes file path as a parameter and returns an instance. This instance pointer has to be stored in the *Document* class to access and close document later. Once we opened the document, it is rendered page by page with the help of the API function *fz\_new\_pixmap\_from\_page\_number*.

---

<sup>3</sup><http://landinghub.visualstudio.com/visual-cpp-build-tools>

<sup>4</sup><http://www.dependencywalker.com>

It simply takes page number and document instance arguments and returns a pointer to the RGB pixmap of the page. In order to convert it to a Qt compliant data structure, an instance of data type *QImage* is created with the constructor that takes pixmap data pointer, pixel counts, and RGB format as arguments. This prevents us from making a data copy which brings an undesired overhead.

An instance of a *Page* class is created for each page of a document. *Page* class on which there is only a *QLabel* object is declared as derived from *QMdiSubWindow* class. *QLabel* can be used for displaying an image by passing a *QPixmap* to its member function *setPixmap()*. In order to achieve this *QImage* instance has to be converted to a *QPixmap* instance by calling *QPixmap::fromImage()* before using *QLabel::setPixmap()* function. When we assign a pixmap to a label, previously allocated memories are no longer needed and can be deallocated since this assignment includes a memory copy.

Pages added to *QMdiArea* object whose details will be explained later. Pointers to *Page* instances of a PDF document are appended to its page list which is a type of Qt linked list class *QList*.

Finally, the pointer to *Document* object stored in the *QList* which is declared in *Main-Window* class so that all the attributes related to a document can be managed in the runtime.

## 4.3 Architecture

From the Figure 4.1, the Unified Modeling Language (UML) diagram of our implementation can be seen. It shows the classes that we created and their Qt base classes which they are derived from. Object compositions are also depicted in the UML diagram. Furthermore, some significant member functions and variables are indicated.

## 4.4 Design Considerations

### 4.4.1 File Management

According to the results of our design workshop, opening multiple documents at the same time is an obvious necessity. For that reason, we implemented the prototype in a way that the user can open multiple PDF documents either separately or simultaneously. With the Qt class, *QFileDialog* it is possible to open a file dialogue and its member function, *getOpenFileNames* returns the paths of the selected files as a string list.

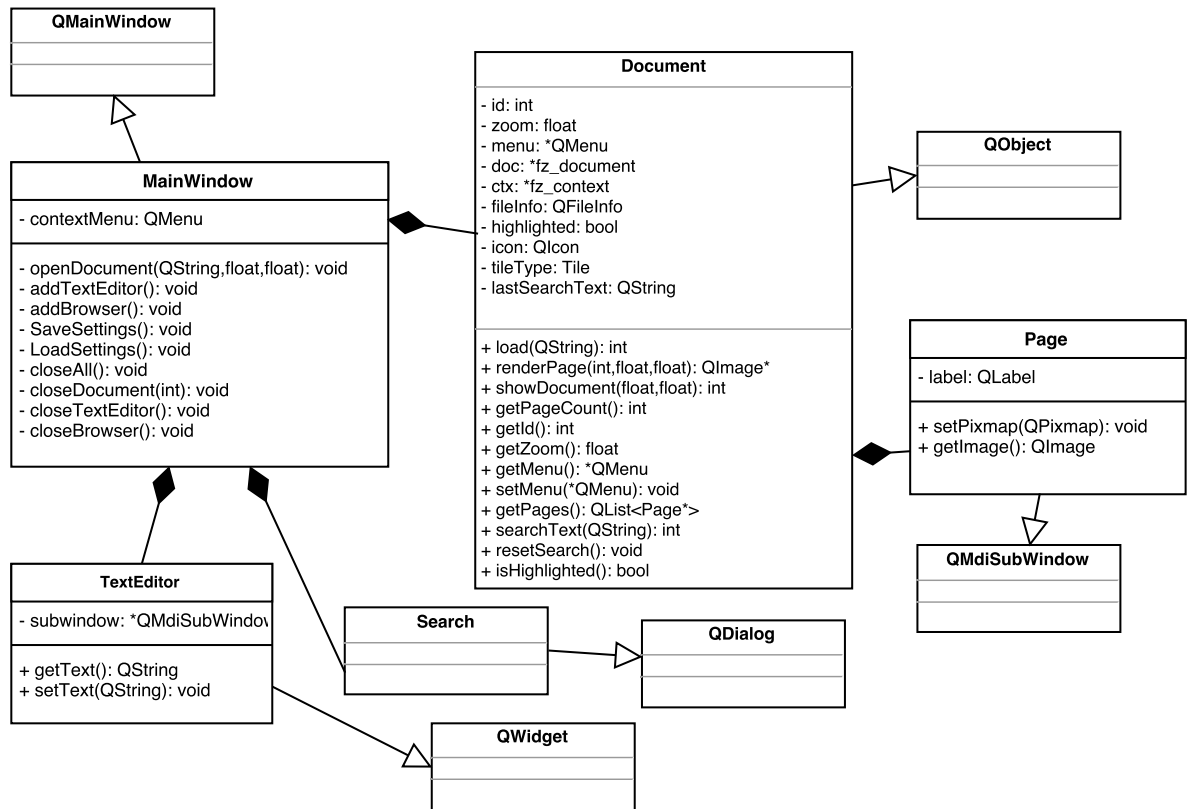


Figure 4.1: UML diagram

Documents can be closed individually or altogether when they are no longer needed by using menu bar or context menu. Entire data corresponding to a closed document is removed from the workspace and dynamically allocated memories are deallocated.

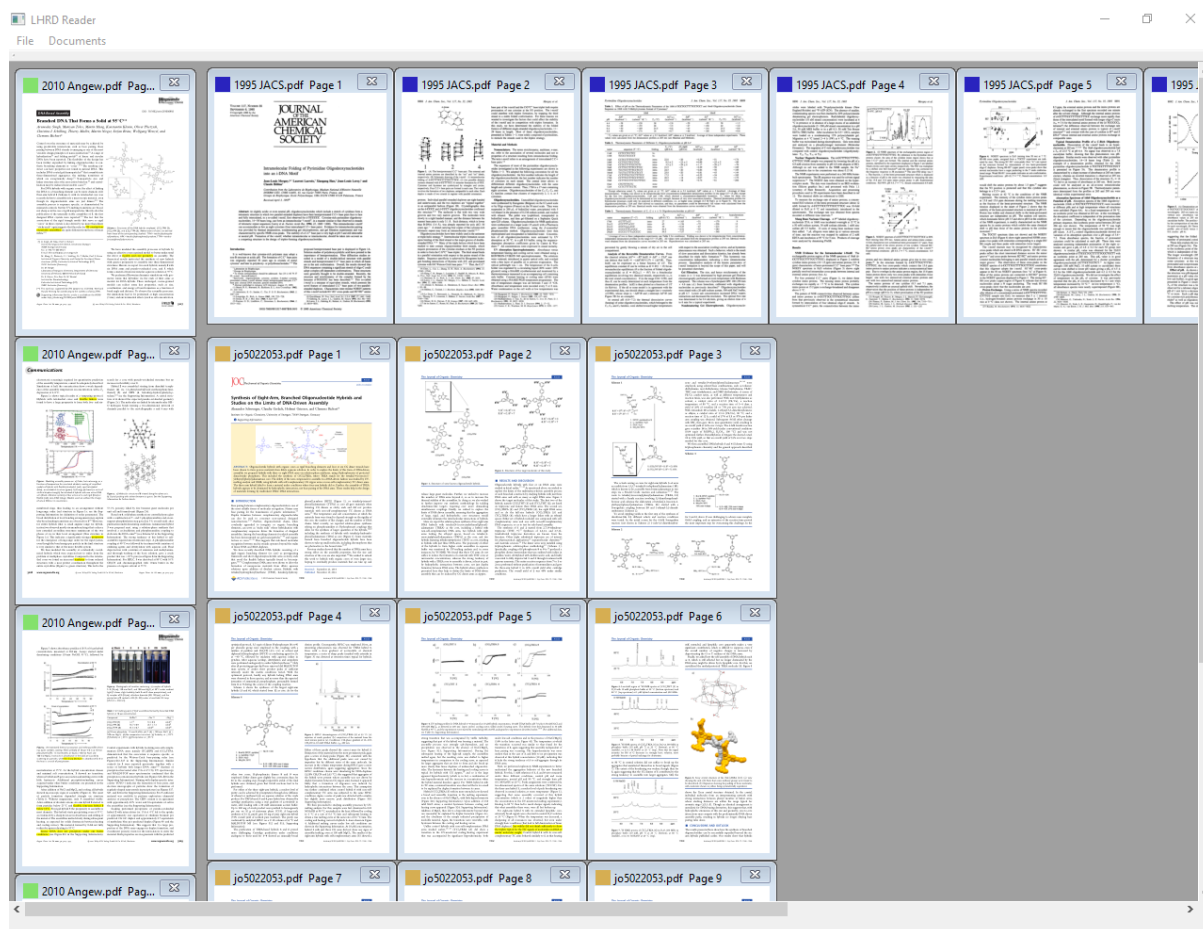
### 4.4.2 Layout

Our design workshop shows that people have very diverse imaginations about arranging a content on LHRDs. Thus our priority was to create a highly customizable environment in which users can realize their preferences easily. As it is explicitly mentioned by four participants (Table 3.2), we implemented GUI in a way that each page is handled independently. This feature is implemented according to Multiple Document Interface (MDI) concept where pages of the documents are added as MDI child windows. Qt provides a class, *QMdiArea* to implement MDI applications. We set it to the *MainWindow* as a *centralWidget*. It is possible to add child windows (*QMdiSubWindow*) with its member function, *addSubWindow()*. Therefore, *Page* objects can be added directly since they are



already derived from *QMdiSubWindow*. All interactions related to a document page such as `show()`, `hide()`, `close()` etc. can be operated through this object.

Taking into consideration that majority of participant preferred horizontal tile when a new document is opened horizontal tile was the default layout. After this point pages can be moved separately or tiled vertically or arranged as a grid layout (Figure 4.2). These operations are implemented by the member functions of *Document* class, *tileHorizontally()*, *tileVertically()*, *tileGrid()*. They calculate new positions of each page and move them to their new locations by traversing through the page list.



**Figure 4.2:** Different layout styles

The last preference of tile type stored in the *Document*. If *Keep Aligned* option is selected, this preference of arrangement is refreshed after a zoom action. Otherwise, positions of pages are preserved as they were before the zoom.

Predefined tile arrangements are done with respect to the first page of a document. For the calculation of dimensions of grid tile, we used the number of its pages. Square-root of the page count is rounded down to calculate column size.

As it is already mentioned by one participant (Figure 3.2), we supported our GUI with scroll bars where the content is larger than it can be shown on one screen. It can be easily tackled by setting vertical and horizontal scroll bar policies of *QMdiArea* object to *ScrollBarAsNeeded*. *QMdiArea* handles scroll interface by itself since it inherits *QAbstractScrollArea* class.

### 4.4.3 Interaction

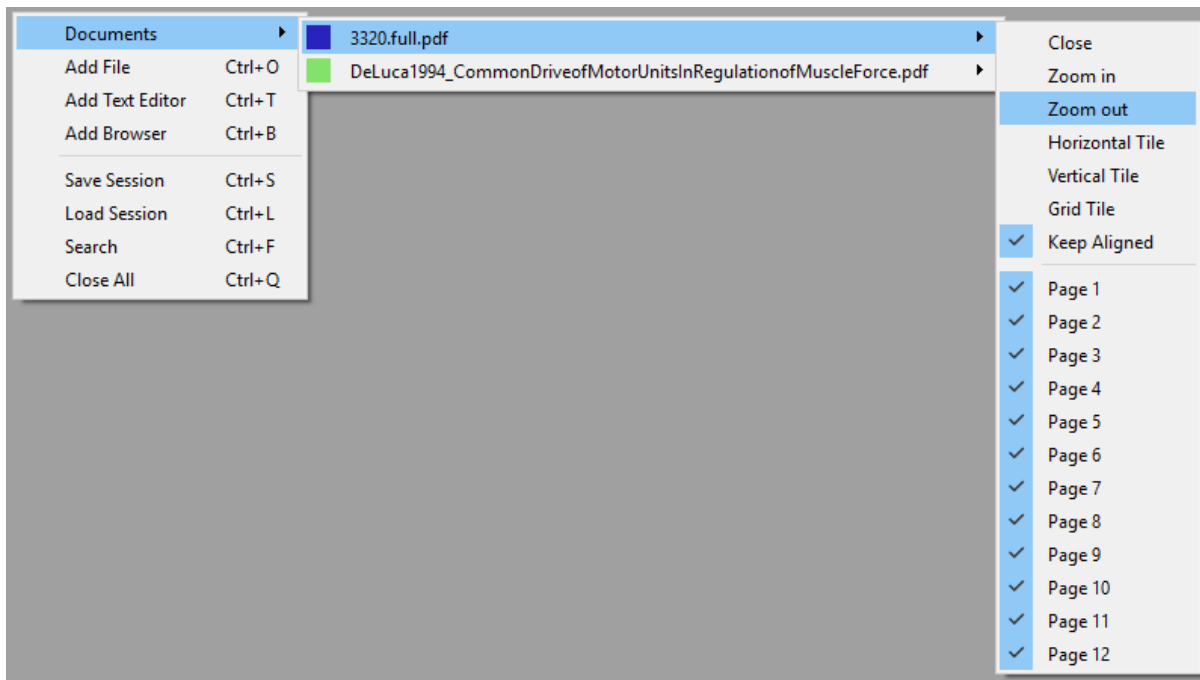
Our main interaction tools are the mouse and keyboard with a touch-pad. It allows users to physically navigate through the content while keeping interacting with the display. Hence, we designed the GUI considering its limitations and advantages.

We implemented a horizontal menu bar with pull-down menu items to provide users an interface which they are familiar with. For this purpose, we used *QMenuBar* class which allows adding menu items (*QMenu*) with *addMenu()*. A *QMenu* instance that consists of document-specific interaction actions is created per document object. This menu is used for closing, zooming, tiling, showing, and hiding pages of a document. Items of the menu are represented by *QAction* class and can be connected to *slots* of respective objects.

Due to the difficulty in moving the mouse pointer on a large display, we offer a context menu as an alternative to the menu bar (Figure 4.3). It appears with a right click where the cursor stands at that moment and provides full control of the GUI. When a right click occurs on *QMdiArea* object, it emits *customContextMenuRequested()* a *signal* which is connected to a *slot* where the context menu is executed. The context menu of *QMenu* type contains same *QAction* items with the menu bar. At initialization time, the constructor of *MainWindow* copies all items of the menu bar.

As can be seen from Figure 4.3, we also provide keyboard shortcuts as an alternative to some menu actions. Some users may choose shortcuts for the functions which they frequently use after some time of usage.

A document can be dragged entirely by pressing shift key during the move. In this case, all the pages of one single document move together, regardless of whether they are tiled or randomly distributed. In order to implement this feature, we used the event handler virtual function, *QWidget::moveEvent()* which receives positions of a widget when a movement event occurs. The moving *Page* object emits a signal to send the differential position to its parent *Document* object. The old position is delivered to the event handler and we have to just subtract its x, y components from the new ones. The signal is only emitted if the shift key is pressed after checking its state with the static function *QGuiApplication::queryKeyboardModifiers().testFlag(Qt::ShiftModifier)*.



**Figure 4.3:** Context menu

Differential x and y positions are received in a *slot* in the parent *Document* object. The pointer of the sender object is checked with *sender()* function and all the other pages are moved by the same amount of received position change. Concerning possible deadlocks, we have to block the signals of the pages that are moved by the code.

#### 4.4.4 Supportive Tools

##### Text Editor

In the design workshop, three participants imagined text editors to take notes. Thus we implemented a text editor by using *QTextEdit* class which enables editing and displaying texts (Figure 4.4). We created a form, called *TextEditor* which consists of a single *QTextEdit* class. When a text editor open event is triggered either by the menus or by the shortcut key, a new instance of is created *TextEditor* whose pointer is added to the list of the *QMdiArea* object. We assigned a random coloured icon for each editor for a better remarkability. The position of a new text editor is set to the next to the mouse cursor, but it can be dragged to anywhere later. A text editor can be closed with its close button which leads its dedicated memory to be freed since we set the windows attribute as *Qt::WA\_DeleteOnClose*. However, this has no effect on the instance list in *MainWindow*. For this purpose, we connected the signal, *QObject::destroyed()* of the text editor to a

slot inside *MainWindow* class to delete the instance from the list when the text editor is deleted.

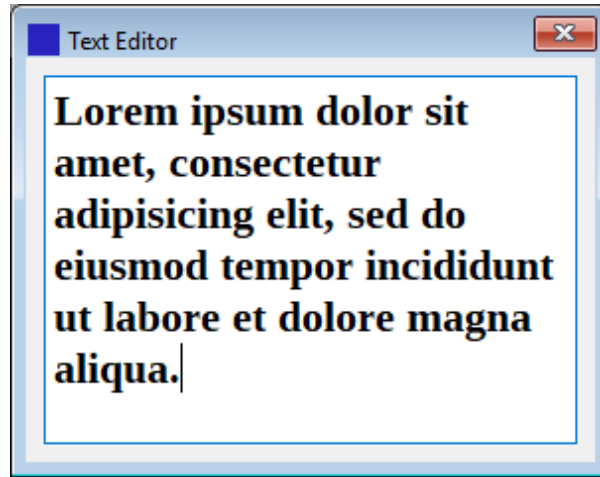


Figure 4.4: Text editor

### Web Browser

Another additional functionality which is mentioned by five participants was an integral web browser. We developed a web browser to browse through *Google Scholar* with the help of the provided *QWebEngineView* class. Upon a request an instance of *QWebEngineView* is created and added as a child window to the MDI area. *QMdiArea::addSubWindow()* takes any *QWidget* derived class as an argument and returns a pointer of *QMdiSubWindow* which is stored in *QList* in the *MainWindow* class. We assigned a random coloured icon for each editor for a better remarkability. The position of a new web browser is set to the next to the mouse cursor, but it can be dragged to anywhere later. For the previously mentioned reason, we connected the signal, *QObject::destroyed()* of the browser to a slot inside *MainWindow* class to delete the instance from the list when a browser is deleted.

A PDF can be imported from the web browser to the PDF reader with just one click. For this purpose, *downloadRequested()* signal of the *QWebEngineProfile* received in the *MainWindow* class. In the reception of the signal, the download request is accepted and the download path is saved with the help of the incoming argument pointer of *QWebEngineDownloadItem* which offers a signal to indicate the end of the download. This signal connected to the slot, *MainWindow::openDownloadedDocument()* to get the file path string and open the downloaded file.

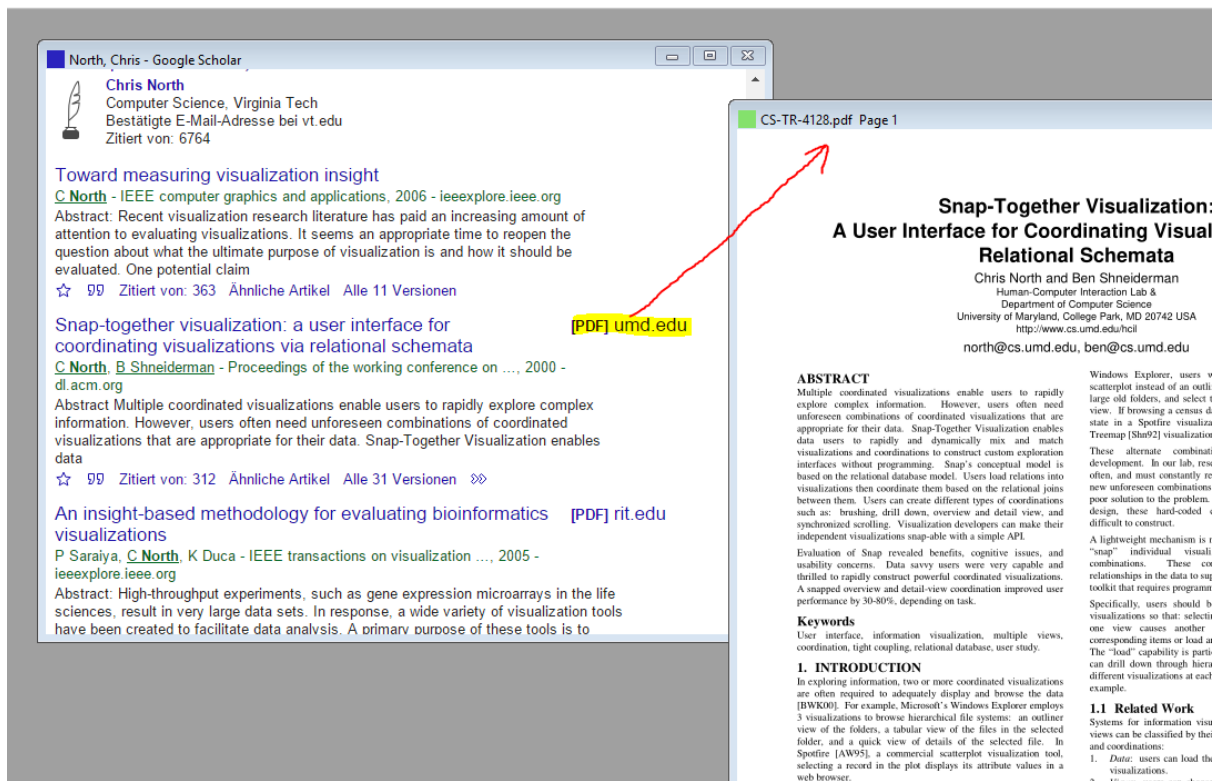


Figure 4.5: Integrated web browser

#### 4.4.5 Search

In order to satisfy participants' demands (Figure 3.9), we implemented a search functionality that enables a search through all the opened documents. As an interface for searching a term, we designed an additional form class, *Search* with a *QLineEdit* object to enter a search string and *QPushButton* object to submit. We used a *QLabel* to display the number of occurrences (Figure 4.6).

*MainWindow* class owns a *Search* object that is shown upon a request via menu or keyboard shortcut (Ctrl+F). The search string is transferred from the *Search* class to *MainWindow* by connecting corresponding signals and slots. When the slot receives a search request, it traverses through the documents list and calls the respective member function of the *Document* class after resetting the previous searches. Similarly, document performs the search page by page. MuPDF offers an API function, *fz\_search\_page\_number()* for searching a term inside a page. It returns a list of rectangles indicating the coordinates of the occurrences. We have to scale these positions with respect to the zoom ratio since the function assumes that zoom ratio is one.

After getting *QImage* object of a page, *QPainter* class is used to highlight the found texts with transparent yellow colour with respect to the returned rectangle list. The original image is saved before the change to restore and remove highlights. We keep the highlight status of a page as a boolean flag. If the flag is set, the search has to be performed again after a zoom operation because positions of the rectangles change. Pressing the "Find" button with an empty string removes all the highlights.

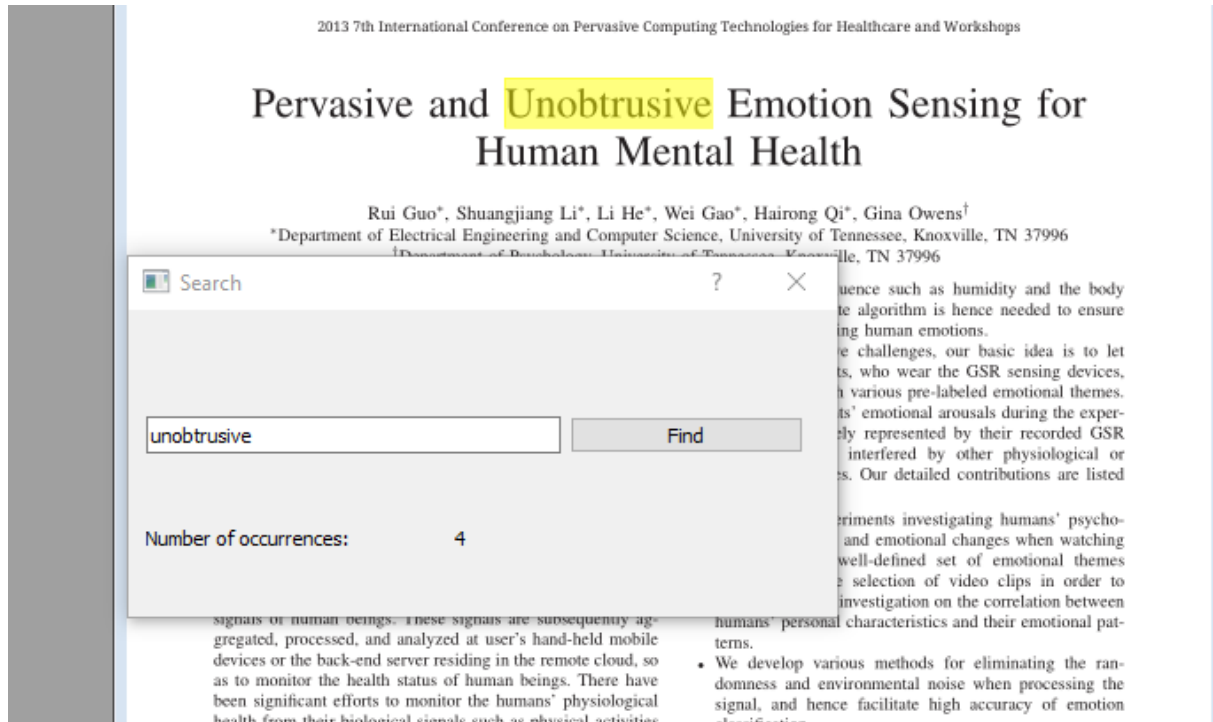


Figure 4.6: Text search

### 4.4.6 Session Handling

Taking into account the design workshop outputs, we give users an opportunity to save their workspaces and settings as mentioned by a participant in the interview part (Section 3.2.6). We used *QSettings* class which created with *QSettings::IniFormat* to implement this feature. The path of the .ini files is determined by the user using file dialog that is shown.

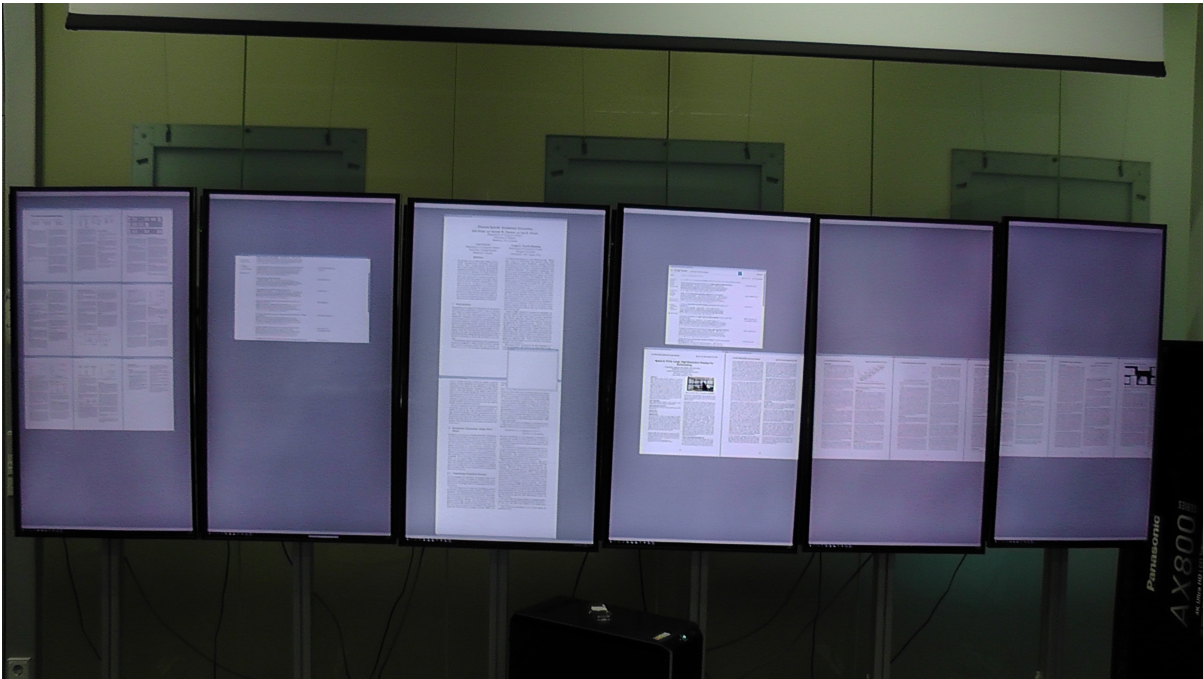
In *MainWindow::SaveSettings()* function, initially position of the main window is saved. Afterwards, file path, zoom ratio, and page positions of the documents in the list are saved. Positions and text content of the text editors are written to the .ini file as well. In addition to the position of the browsers, its URLs are saved to restore last visited web page later.



In order to load session settings, the function, *MainWindow::LoadSettings()* is called. Users can select any .ini file, that they saved before, from their file system. Properties of the items are read from the file in the same order as the are saved. Documents are opened with respect to the file path list and their pages are moved to the stored positions.

## 4.5 General View

As shown in Figure 4.7, an overview of a working prototype on an LHRD can be seen. The LHRD consists of six 50" 4K Panasonic TX-50AXW804 screens with a resolution of  $3840 \times 2160$  (88 PPI). They are arranged next to each other in portrait mode so that we can have a display with a dimension of 4.04 x 1.13 meters.



**Figure 4.7:** A general view of a working prototype





## 5 Evaluation

We conducted a collaborative sensemaking user study with twenty participants to evaluate the usability and performance effects of our prototype in comparison with a standard PDF reader. Our hypothesis was that utilization of our PDF reader prototype enhances performance in task completion and reduces cognitive demand. We defined two conditions in which the tasks are performed, *Condition A* where participants use our prototype, and *Condition B* which is set for the participants who use a standard PDF reader.

### 5.1 Demographics

We recruited 20 participants in the age range 20-32 (*Mean Value: 25.75, Standard Deviation: 2.91*) by using our contacts at the university (see Table 5.1). To that end, we created a Google Form<sup>1</sup> for the registration and time slot selection and distributed via e-mail.

The participants consist of entirely students and participated on a volunteer basis. We compensated their efforts and time with candies and chocolates after the session. Concerning the gender distribution of the participants, the majority of them was male with a ratio of 75%. Since the task had to be solved in pairs, we formed ten pairs in total. Six of the pairs already knew each other and came with their own partners. For the rest, we assigned an appropriate partner according to their time slot preferences in our registration form. As can be seen in Table 5.1, we assigned participant and pair ids to be referred later in this thesis. We distributed the pairs equally for the two conditions, five pairs per condition.

---

<sup>1</sup><https://www.google.com/forms/about>

Pair ID	Participant ID	Age	Gender	Condition
1	1	20	male	A
1	2	27	male	A
2	3	25	male	A
2	4	26	male	A
3	5	29	male	A
3	6	25	male	A
4	7	27	female	B
4	8	25	male	B
5	9	28	male	B
5	10	28	male	B
6	11	27	male	B
6	12	25	male	B
7	13	26	female	B
7	14	26	male	B
8	15	29	female	A
8	16	21	female	A
9	17	24	male	A
9	18	24	male	A
10	19	32	female	B
10	20	21	male	B

**Table 5.1:** Participants in the collaborative sensemaking study

## 5.2 Apparatus

The LHRDs, which we provide to the users, comprises of six horizontally-tiled 50" 4K Panasonic TX-50AXW804 screens with a resolution of  $3840 \times 2160$ . They measure in total 4.04 x 1.13 meters, and their lower edges are 76 cm from the ground.

The participants are able to interact with the set-up using Logitech Wireless Touch Keyboard K400 Plus with built-in multi-touch touchpad which allows horizontal and vertical scrolling with only two fingers. As an alternative, the set-up is equipped with a Logitech M185 Wireless Mouse that can be used on the round table in front of the screen as depicted in Figure 5.1.

For the users who work in the *Condition A*, we offer our prototype which is described in Chapter 4. The application is shown in full screen mode by default when it is opened.

We prevent the users from resizing or moving the main window of the application by hiding the window frame.

We installed the latest version of the Adobe Acrobat Reader DC (2017.012.20098)<sup>2</sup> for the *Condition B*. It provides a tabbed view for multiple documents initially; however, it is possible to separate them by dragging from the tab bar.

We set the mouse pointer to the largest size with the *Windows Inverted* scheme to achieve more visibility. Additionally, we activated the option that shows the location of pointer when the CTRL key is pressed to avoid loss of mouse pointer on LHRDs.



**Figure 5.1:** Study materials: LHRDs, consent forms, pens, round table, wireless keyboard and mouse

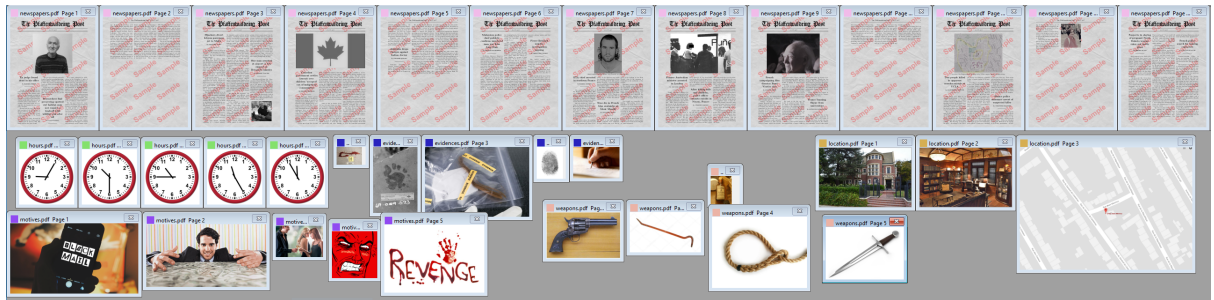
## 5.3 Methodology

As proposed by the previous works [Goy13; WKL+16], we developed our methodology based on a crime analysis as a sensemaking task where the information is foraged in an iterative process as proposed by Pirolli and Card [PC05].

<sup>2</sup><https://acrobat.adobe.com>

### 5.3.1 Data set

We designed a crime mystery task as a data set to be solved participants of the user study. For this purpose, we made a story of a crime-solving puzzle and embedded the necessary information in some irrelevant data so that the generated documents could be distributed on the LHRDs. The original puzzle was taken from a website<sup>3</sup> which provides various brain teasers and adapted to our study. The task was finding the murderer of an ex-judge who found dead in his office after he had given a party at his mansion. There are five suspects whose statements establish the ground truth which is hidden in a form of newspaper articles. Derived from the Wikinews<sup>4</sup> articles, we generated 24 newspaper articles, only 7 of which contain the useful information. The participants are expected to eliminate those irrelevant data and retrieve the profitable knowledge. The articles are presented on the first pages of 12 newspapers which have chronological dates. To make the articles look like a real newspaper, we used a website<sup>5</sup> that generates mock newspapers. We combined these newspapers as one single PDF file with 17 pages (Figure 5.2). In addition to the newspapers we enriched the data set by providing some trivial visual information in PDF format about weapons, motives, incriminating clues, entrance times of the suspects; and about the location of the crime scene.



**Figure 5.2:** Collection of the dataset

### 5.3.2 Preliminary Study

Before starting to the main user study, we conducted a preliminary study to reveal deficiencies of the methodology. By this means, we aimed to estimate the actual workload of the task as well. Moreover, we could also unveil the inconsistencies that might occur in the dataset.

<sup>3</sup><https://www.braingle.com>

<sup>4</sup><https://www.wikinews.org>

<sup>5</sup><https://www.homemade-gifts-made-easy.com/newspaper-generator-plus.html>

Due to the shortage of volunteers, the study is conducted with only one person (male, 29) instead of a pair. We decided to operate this session in the *Condition A* to evaluate also the prototype. Nearly same materials with the main study but without a wireless mouse are provided to the participant.

He successfully utilized the interface, eliminated the noise data by hiding unnecessary pages. As a result, it took 40 minutes for him to accomplish the task with a correct answer. He pointed to a few minor inconsistencies which made him confused in the noise information. Owing to this, we had an opportunity to correct this ambiguousness for the primary study. He stated his discomfort due to the absence of a mouse and found it difficult to scroll with only using the touchpad. Therefore, we decided to provide a wireless mouse in addition to the keyboard with a touchpad.

This preliminary study confirmed that the task can be accomplished in a reasonable time. With the help of this information, we estimated the duration of a session approximately one hour.

We observed that some minor improvements have to be applied to the prototype software. Previously, accessing the menu of a document was only possible via the main context menu which brings an overhead for the user. We facilitated that interface by adding a functionality of separate context menus for each document. Another problem was that a smaller page was hidden by a bigger active window. To solve this issue, we added *Bring to top* option for all documents. Similarly, Text Editor windows are set with the attribute of *Always Top* so that they would not disappear when a window on which they lay is activated. The participant had difficulties while he was moving the entire pages of a document by pressing the Shift key. At that time the Shift key had to be pressed during the entire move. After the revision, it is enough to press the Shift key at the beginning of the movement. Another revision was made on the tile operations which priorly redisplayed the hidden pages of a document before tiling. Since it ruined the arrangements user made, we fixed this problem as well.

### 5.3.3 Procedure

Participants are welcomed one by one and introduced to their partners if they do not already. They signed a consent form as an agreement for the study and filled a small demographics form to collect information about their age, gender, and profession.

For the pairs who participate in the *Condition A*, we have to explain how to interact with our prototype. To that end, we introduced how a document can be opened, closed, tiled, and zoomed by using the context menu or menu bar. As distinct from the standard PDF readers, either pages of a document can be arranged separately, or they can be moved

as a whole. Those functions have to be presented to the participants before starting the primary task. The users in *Condition B*, were already familiar with the Adobe Acrobat Reader. Moreover, they gained experience of separation of tabbed documents through the demo task.

To familiarize the participants with the data set and the interface, we prepared a demo data set to be solved before starting the main task. Similarly to the real data set, it consists of 5 newspapers as separate PDF files with different dates, and corresponding days of a calendar for these days. Demo task consists of rearranging the newspapers chronologically and matching with the respective calendar page. Grouping calendar date and the corresponding newspapers helps the pairs to develop familiarity with the mobility of the documents.

Participants are told that they are able to utilize the mouse and the wireless keyboard with a touch-pad to interact with the set-up by moving freely or standing at the table. We do not restrict how the interaction tools are shared by the individuals, and how they distribute the workload.

Primarily, the participants are informed that their task was to find out the murderer of the ex-judge Pierre Bernard using the clues we had given. As a part of the task description, they are briefed about the clues which consist of newspaper articles; and images related to the location, motivations, weapons, and the incriminating clues of the suspects. During the introduction of the crime puzzle solving task, we informed the pairs that we added some unrelated information which they should eliminate and retrieve the useful information. We gave a crucial clue that the suspects do not lie about their witnessing in their statements to the police or the press reporters.

We made answer sheets with space for taking notes and writing final answer available to the participants. We told the pairs to submit their answer sheets with the name of the murderer when they are ready and sure about their decisions.

### 5.3.4 Measures

We determined four types of measurement sources to evaluate our PDF reader prototype: Answer sheets for the accuracy, video recordings, mouse logs, and post-task surveys about usability and workload.

#### Task Performance

For the analysis of the task accuracy, we used answer sheets with the name of the murderer and notes. Intermediate arguments in the notes help us to judge how they

reached the final answer. We evaluated these answers in a binary manner as correct or wrong. Another indicator of the performance is TCT which is extracted from the video recording. The entire session starting from the demo task is recorded by a Panasonic HD video camera. We measured the time between when they started to solve the puzzle and when they submitted the answer sheet.

### Input logging

We logged mouse and keyboard actions of the participants to analyse their interaction behaviours. The software, MiniMouseMacro<sup>6</sup> was used in both conditions to record input events with their timestamps. We are basically interested in number of mouse clicks and cumulative distance of mouse-dragging. When a record is started, the software creates a raw file and outputs the input events with their coordinates and timestamps. For the calculation of the results, this raw file can be easily converted to CSV<sup>7</sup> format. We processed these data in the form of Excel Sheet so that differences between coordinates of the mouse move events can be calculated and magnitudes of these vectors can be summed up. Furthermore, number of mouse click can be calculated by counting the number of mouse release events.

### System Usability Scale

After the completion of the task, we requested participants to fill a SUS survey to evaluate the usability of our prototype. The SUS which gives a quantitative result about the usability of a system is proposed by Brooke et al. [Bro+96]. It consists of ten statements to be rated on a scale of 1–5 between *Strongly disagree* and *Strongly agree*. Finally, a SUS score from 0 to 100 is obtained.

### Task Workload

For the measurement of the task workload, we used NASA TLX [HS88] form to be filled by the participants after the session. NASA TLX technique helps to assess subjective workload of a task in six domains: mental demand, physical demand, temporal demand, performance, effort, and frustration. To calculate TLX score from 0 to 100, we used a modification, Raw NASA TLX [Har06] which skips weighting of the contributing factors.

---

<sup>6</sup><https://sourceforge.net/projects/minimousemacro>

<sup>7</sup>Comma-separated values

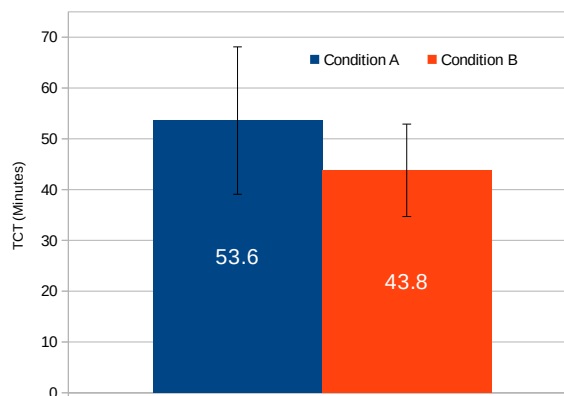
## 5.4 Results and Analysis

The comparative results of our evaluation study are presented with their mean values in this section. We performed a two-tailed t-test to check whether the differences in two conditions are statistically significant. Additionally, Pearson correlation coefficient is calculated to determine correlations between different metrics.

### 5.4.1 Performance

Only three of the participant pairs were able to complete the task with the correct answer. Two pairs in *Condition B* and one pair in *Condition A* found out the name of the real murderer. Consequently, our prototype did not increase the task completion performance in terms of accuracy. For a better understanding, we analysed the notes on the answer sheets that we collected from the participants. Five of the seven unsuccessful pairs (three in *Condition A*, two in *Condition B*) were able to narrow down the five suspects to two suspects based on the clues. Due to the fact that they overlooked two important clues, the entrance time or the weapon of the murderer they came up with the wrong answer. The remaining two pairs gave completely irrelevant answers.

We obtained TCTs from the analysis of video recordings. Less TCT indicates better performance. As can be seen in Figure 5.3, according to their mean values, it seems that the pairs in *Condition B* performed slightly better with a less average TCT ( $M = 43.8$  minutes,  $SD = 9.09$ ) than the participants in *Condition A* ( $M = 53.6$  minutes,  $SD = 14.53$ ). However, the t-test revealed that TCT differences between two conditions are statistically insignificant ( $t = 1.278$ ,  $p = 0.237$ , insignificant at  $p < 0.10$ ).



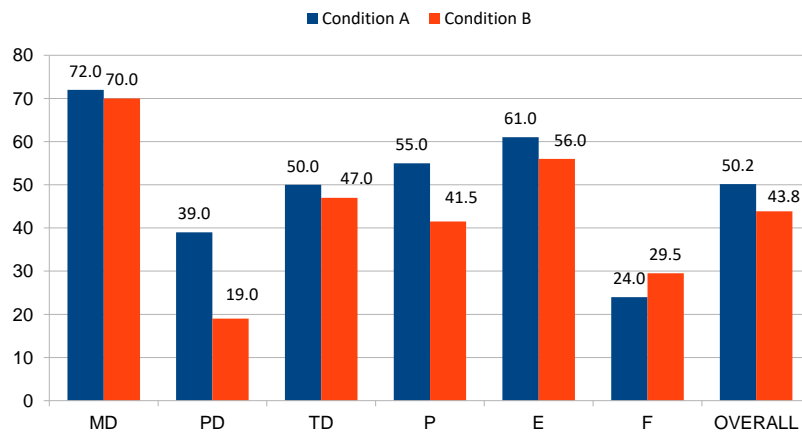
**Figure 5.3:** Mean values of TCTs with standard deviations



The performance results contradict with our hypothesis that utilization of our prototype enhances performance in task completion comparing to a standard PDF reader.

### 5.4.2 Task workload

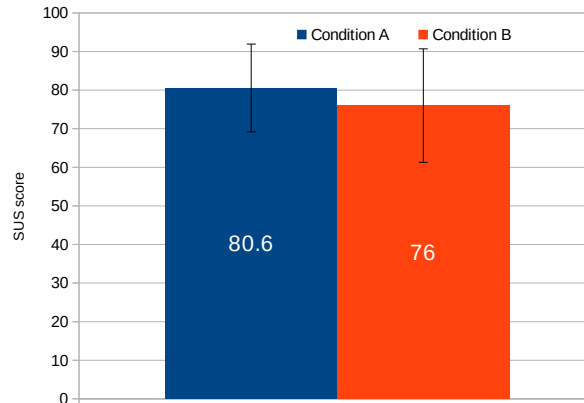
Figure 5.4 shows mean values of the NASA TLX scores of six subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration) and the overall result for both conditions. The participants who completed their tasks with our prototype and the Adobe Acrobat Reader rated with an overall average score of 50.2 ( $SD = 7.9$ ) and 42.8 ( $SD = 10.7$ ) respectively. Comparative results demonstrate that usage of the PDF-Prototype had no significant effect on the overall perceived workload ( $t = 1.497$ ,  $p = 0.151$ , insignificant at  $p < 0.10$ ). On the other hand, average score for the physical demand is significantly increased in *Condition A* ( $M = 39$ ,  $SD = 26$ ) in comparison to *Condition B* ( $t = 2.091$ ,  $p = 0.051$ , significant at  $p < 0.10$ ). We deduce from this that the prototype we developed made the task more physically demanding.



**Figure 5.4:** Mean values of NASA TLX scores

### 5.4.3 Usability

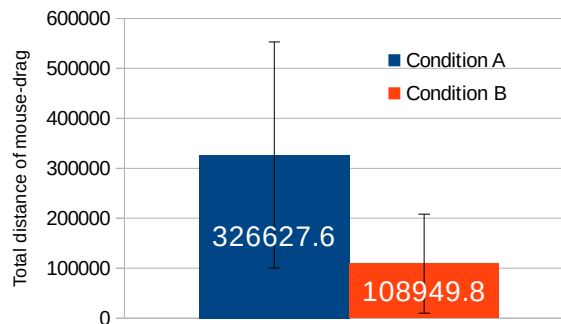
The scores of the SUS questionnaires are calculated individually for each participant and averaged for both conditions separately as depicted with their standard deviations in Figure 5.5. Although *Condition A* scored slightly better than the Adobe Acrobat Reader, t-test demonstrates that the prototype had no significant effect on the usability for the given task ( $t = 0.550$ ,  $p = 0.589$ , insignificant at  $p < 0.10$ ).



**Figure 5.5:** Mean values of SUS scores

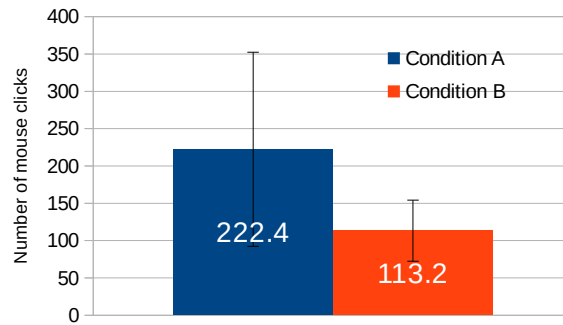
### 5.4.4 Interaction and Usage of Display Space

According to the input log records, in *Condition A*, the mouse cursor travelled, on average, more than twice as much drag distance as in *Condition B* ( $t = 1.971$ ,  $p = 0.084$ , significant at  $p < 0.10$ ) (Figure 5.6). Similarly, in *Condition A*, the key-logger recorded on average nearly twice as many mouse clicks as in *Condition B* but with a less significance ( $t = 1.777$ ,  $p = 0.113$ , insignificant at  $p < 0.10$ ) (Figure 5.7). Due to the higher mobility features of the PDF reader prototype such as movable pages, usage of input modalities is significantly increased. Another reason for the less interaction metrics in *Condition B* is that the participants used the mouse wheel for scrolling which was the main navigation type for Adobe Acrobat Reader and is not recorded by the logger.



**Figure 5.6:** Mean values of sum of the mouse-drag distance in pixels

A Pearson Product-Moment calculation unveiled that in *Condition A* there is a strong positive correlation between the TCTs and mouse-drag distances ( $R = 0.921$ ,  $p = 0.026$ , significant at  $p < 0.10$ ) as well as between the TCTs and mouse click counts



**Figure 5.7:** Mean values of total number of mouse clicks in both conditions

( $R = 0.850$ ,  $p = 0.068$ , significant at  $p < 0.10$ ). This situation changes in *Condition B* where there are only weak relationships between those values, ( $R = 0.230$ ,  $p = 0.709$ , insignificant at  $p < 0.10$ ) and ( $R = 0.058$ ,  $p = 0.926$ , insignificant at  $p < 0.10$ ) respectively.

For a more detailed analysis, we extracted users' interaction behaviours from the video recordings. In both two conditions, we observed that the wireless keyboard was rarely used. For dragging or scrolling documents, the pairs chose to use the wireless mouse on the round table. Only two participants from separate pairs who had Adobe Acrobat Reader used Keyboard up and down buttons few times for scrolling. Another two people tried to use the keyboard once but then never used it again.

Type of the interface and layout styles determined the way of how the pairs interacted with the set-up. The Adobe Acrobat Reader user pairs developed very similar arrangement approaches. All of them maximized the newspaper file on one of the closest screens, either third or fourth one so that they could read the document without leaving the table. Three of five pairs who performed with Adobe Acrobat Reader, distributed six documents to each screen as can be seen in Figure 5.8. The rest of the pairs preferred to collect all the documents on the nearest four screens. Another common behaviour amongst the Adobe Acrobat Reader users was that they did not change the window arrangements which they initially made. This resulted in less mouse drag distance in comparison to *Condition A* (Figure 5.6).

We observed relatively diverse layout arrangements amongst the participants who worked with our prototype. However, the general attitude was to eliminate the irrelevant newspaper articles and to collect useful information in a focus area. Three of five pairs that worked with the prototype used page hiding functionality to omit unrelated articles. One pair chose to group irrelevant pages in another area out of focus. Another pair kept the newspapers file as it is after a grid tile. They just arranged the document to avoid discontinuities by bezels.



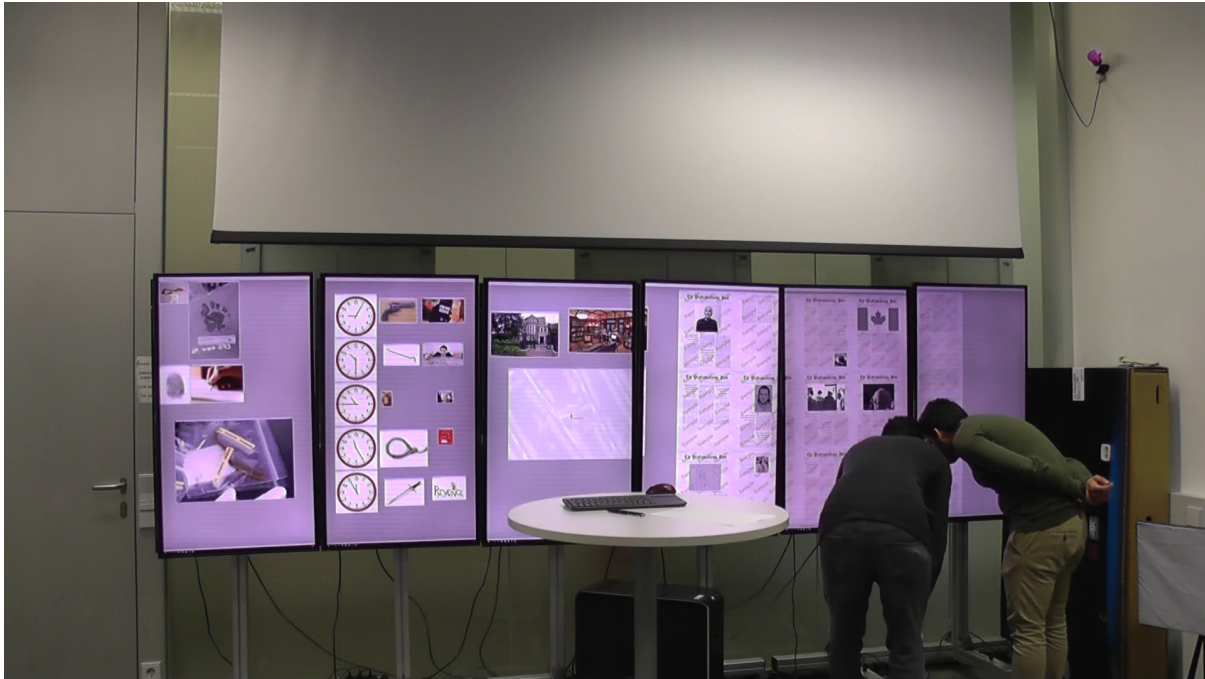
**Figure 5.8:** Typical layout in *Condition B*

All of the prototype users zoomed in the newspapers file at least once. Three of these pairs used grid tile to have an initial form while the other two pairs preferred the horizontal tile that comes as default. None of them tiled the pages intentionally after they created their customized arrangements.

In contrast with the Adobe Acrobat Reader users who stood around the round table, *Condition A* couples actively used physical navigation. In four of five *Condition A* sessions, both pairs stood and walked in front of the display during the majority of their TCTs. They went back to the table only for taking notes, discussing, and using the mouse. The remaining couple shared interaction and physical navigation tasks; one of them controlled the mouse pointer at the table while the other one was moving around the displays and giving commands.

Three of five the couples who worked with our prototype preferred to fit the focus materials at their eye levels for a more comfortable view. Differently, the other two couples chose to lean forward to see the pages below their eye levels instead of changing layout as can be seen in Figure 5.9.

The pages of a document are statically linked together in the Adobe Acrobat Reader; therefore the couples who used it had no opportunity to move or group single pages of the supporting images. They just skimmed these images regarding motivations, weapons, incriminating clues, and entrance times of the suspects. On the other hand, since we



**Figure 5.9:** The pages below eye level *Condition A*

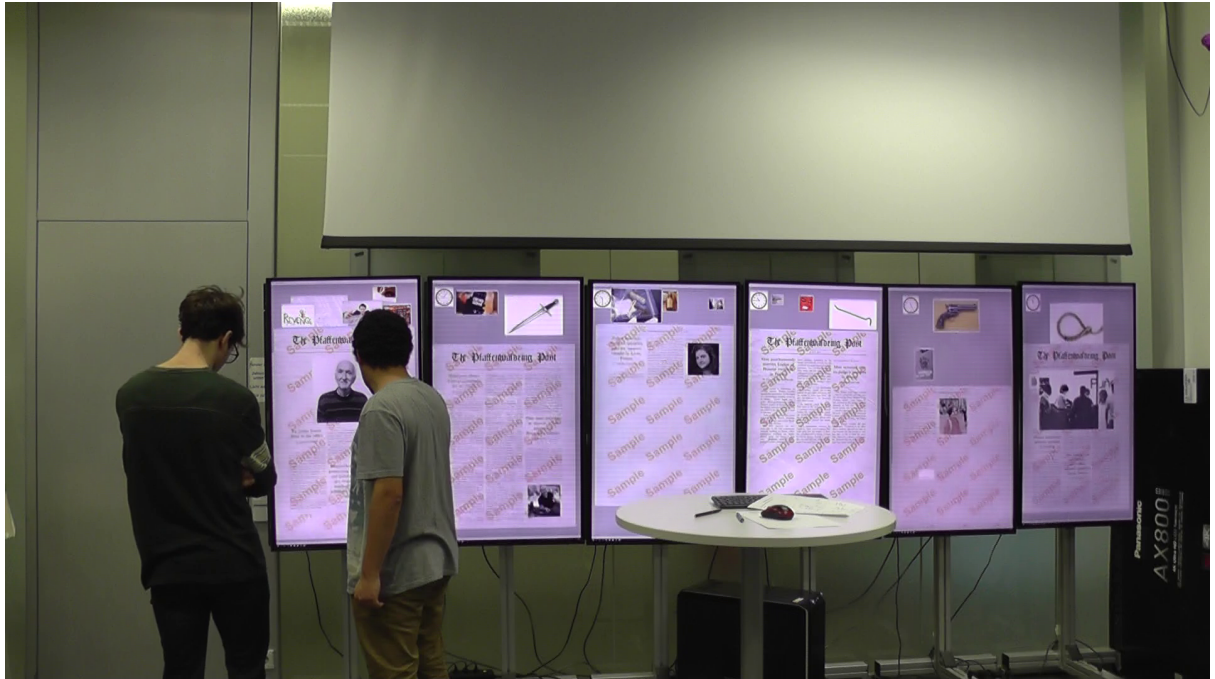
provide movable pages in our prototype, two of the participant couples who performed the task in *Condition A*, took the advantage of mobile pages by grouping them with the statements of the suspects. One of these couples preferred to drag them onto the place where they are referenced from. The other group collected the related images on the top of the page as depicted in Figure 5.10.

## 5.5 Limitations

With a limited number of participants, it is hard to reach a realistic conclusion. Due to the shortage of volunteers and limited time we could only recruit twenty people, five pairs per condition, which may lead to error-prone results.

We were not able to assess workload of the task accurately before the primary studies. The preliminary study in which the participant accomplished his task successfully did not reflect the reasonableness of the task well. We could not achieve an extensive investigation for the data set and the task with only one participant-preliminary study due to the time limitation. Consequently, only three of ten couples could come up with the correct answer. It might affect our study to produce a healthy result with our current measures.





**Figure 5.10:** Grouping of the supporting images in *Condition A*

None of the participants was native speakers of the English language, but we did not collect any data about their proficiency levels. Some of the participants noted that their comprehension in English was not enough to understand some statements. For instance, one couple was unaware of the meaning of revolver, one of the weapons in the data set. It might be another factor that unintentionally influenced our results.

## 5.6 Discussions

The results of the evaluation user study do not support our hypothesis that usage of our prototype enhances performance in task completion and reduces cognitive demand comparing to a standard PDF reader. In this section, possible reasons for this outcome are investigated.

The mobility of single pages and higher flexibility compared to Adobe Acrobat Reader required more intense usage of input tools as can be seen in Figure 5.6 and Figure 5.7. In *Condition B*, pairs did not change their layout preferences after they distributed the six documents to screens within first few minutes of their TCTs. Besides, the strong correlations between interaction frequencies and the TCTs in only *Condition A* support this argument. We suppose that it is one of the factors which increased average TCT in *Condition A*.

In order to explore reasons behind the worse TCT results occurred with our prototype, we analysed video recordings. We examined more particularly three couples (1, 3, 9) who increase the average TCT (Figure 5.3) in *Condition A* with TCTs of 68, 60, and 64 minutes respectively. We noticed that it took for them to settle down with an initial arrangement and to focus on the newspaper articles 7, 10, and 8 minutes respectively. We also observed that Pair 1 and 3 confused with hiding pages and closing a document, mistakenly, they closed the document and ruined their arrangement. Furthermore, Pair 1 and 9 spent their times matching supporting images and suspects' statements in the newspapers. *Keep Aligned* option which rearranges pages after a zoom was another factor that confused Pair 1 and 9 and destroyed their layout.

Despite the fact that the pages of a document are marked with same coloured icons, and page numbers are written on their window bars, our prototype was unsuccessful to emphasize the integrity of a document. For instance, Pair 2 overlooked some pages because they were outside of the visible area which can be accessed by scrolling. Obviously, this inadequacy decreased performance of our prototype.

As a result, we argue that the novelty and higher customizability of the prototype prevented us from achieving enhancements in TCT results in *Condition A* compared to *Condition B*.

As presented in Section 5.4.4, in *Condition A*, users were standing or moving in front of the displays in more than half of their TCTs while the participants who performed in *Condition B* stood mostly around the round table. We believe that it is one of the factors of receiving significantly higher NASA TLX scores in physical demand sub-scale for *Condition A* than for *Condition B* (Figure 5.4).

Participants who never worked with LHRDs before orally expressed after the session that it excited their interest to use such a set-up. It happened in both conditions. We assert that rating usability of the LHRDs rather than the interface can be an explanation of the reasons why we received quite close SUS scores.





## 6 Conclusion

In this thesis, we designed, implemented, and evaluated a PDF reader as a working prototype that works on LHRDs, with the aim of enhancing performance and usability compared to the conventional PDF readers.

We conducted GUI design elicitation workshops with twelve participants with a focus on researchers as a professional group. After the elicitation of design concepts through user-centred design workshops, we collected and analysed most promising and reasonable ideas which can be realized within the framework of this thesis.

In accordance with the suggestions and requirements that we received in the workshops, we implemented a GUI in C++ for our prototype in which we use an open source PDF-renderer. To offer more customizability to the users, we enable the pages of a document to be moved independently. The pages can be zoomed, tiled horizontally, vertically, and as a grid; or hidden if they are not necessary. Moreover, we implemented additional features which were mentioned in the workshops such as searching a keyword, built-in browsers, and text editors. The PDF files can be transferred from the integrated browser to the PDF reader with just one click on their links. We made a menu a bar and context menus available to the users for their interaction.

As described in detail in Chapter 5, for the evaluation of the PDF reader prototype compared to a conventional PDF reader in terms of performance, cognitive load, and usability, we conducted a collaborative sensemaking user study with twenty participants. We divided equally the participants in pairs into two conditions; *Condition A* with the prototype, *Condition B* with a standard PDF reader. We requested the to solve a crime story that we created as a sensemaking task.

The results of the evaluation user study regarding our measures do not support our arguments that the prototype would enhance performance, usability and reduce cognitive load. Apart from the limitations of the user study which are mentioned in Section 5.5, we examined the possible grounds for this outcome in Section 5.6. In conclusion, we believe that the novelty and higher customizability of the prototype lead it to show only insignificant changes in proportion to Adobe Acrobat Reader in terms of TCT. Furthermore, the prototype requires more physical interaction hence we received only insubstantial NASA TLX scores compared to the standard PDF reader.

Besides, unfamiliarity with LHRDs obscured to receive distinguishable SUS scores, and our prototype did not produce significant enhancements in the usability domain for the given task.

This thesis contributes to a better understanding regarding GUI-design and implementation for document viewing on LHRDs and their possible influences on user experience and performance.

### 6.1 Future Work

The PDF reader prototype which is proposed in this thesis can be enhanced in some ways. The evaluation user study revealed that setting same coloured icons to the different pages of a document is far from highlighting the integrity of the document. Furthermore, individually handling all the pages is not desired by the users in all cases. In the current implementation, the user has to press the Shift key to move the entire document which might be too tedious for perpetual tasks. This feature could be implemented as an optional choice, and there could be a better solution for grouping documents.

Additionally, present version does not support text selecting and highlighting features; they can be implemented in the future.

Once the improvements mentioned above are made, another user study with more reasonable data set by taking into consideration previous limitations (Section 5.5) can be conducted to re-evaluate the prototype in its actual state.

# Bibliography

- [AEN10] C. Andrews, A. Endert, C. North. “Space to think: Large, High-Resolution Displays for Sensemaking.” In: *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10* April 10-15 (2010), pp. 55–64. DOI: [10.1145/1753326.1753336](https://doi.org/10.1145/1753326.1753336). URL: <http://portal.acm.org/citation.cfm?doid=1753326.1753336> (cit. on p. 19).
- [AMB+17] I. Avellino, W. E. Mackay, M. Beaudouin-lafon, U. Paris-saclay, F.-. Orsay. “CamRay : Camera Arrays Support Remote Collaboration on Wall-Sized Displays.” In: (2017) (cit. on p. 18).
- [ATK+05] B. A. Ahlborn, D. Thompson, O. Kreylos, B. Hamann, O. G. Staadt. “A practical system for laser pointer interaction on large displays.” In: *Proceedings of the ACM symposium on Virtual reality software and technology - VRST '05* (2005), p. 106. DOI: [10.1145/1101616.1101637](https://doi.org/10.1145/1101616.1101637). URL: <http://portal.acm.org/citation.cfm?doid=1101616.1101637> (cit. on p. 21).
- [Bau01] P. S. Baudisch, N. Good. “Focus Plus Context Screens: Combining Display Technology with Visualization Techniques.” In: *Proc. of UIST 3.2* (2001), pp. 31–40. DOI: [10.1145/502348.502354](https://doi.org/10.1145/502348.502354) (cit. on p. 18).
- [BBB14] X. Bi, S. Bae, R. Balakrishnan. “WallTop: Managing Overflowing Windows on a Large Display.” In: *Human-Computer Interaction* November 2014 (2014), pp. 1–59. ISSN: 0737-0024. DOI: [10.1080/07370024.2013.812411](https://doi.org/10.1080/07370024.2013.812411). URL: <http://www.tandfonline.com/doi/abs/10.1080/07370024.2013.812411> (cit. on p. 18).
- [BBCM08] B. P. Bailey, J. T. Biehl, D. J. Cook, H. E. Metcalf. “Adapting paper prototyping for designing user interfaces for multiple display environments.” In: *Personal and Ubiquitous Computing* 12.3 (2008), pp. 269–277. ISSN: 16174909. DOI: [10.1007/s00779-007-0147-2](https://doi.org/10.1007/s00779-007-0147-2) (cit. on p. 22).
- [BEK+13] L. Bradel, A. Endert, K. Koch, C. Andrews, C. North. “Large high resolution displays for co-located collaborative sensemaking: Display usage and territoriality.” In: *International Journal of Human Computer Studies* 71.11 (2013), pp. 1078–1088. ISSN: 10715819. DOI: [10.1016/j.ijhcs.2013.07.004](https://doi.org/10.1016/j.ijhcs.2013.07.004) (cit. on p. 19).

- [BGC10] S. Branham, G. Golovchinsky, S. Carter. “Let’s go from the whiteboard: supporting transitions in work through whiteboard capture and reuse.” In: *Chi 2010* (2010), pp. 75–84. DOI: [10.1145/1753326.1753338](https://doi.org/10.1145/1753326.1753338). URL: <http://dl.acm.org/citation.cfm?id=1753338> (cit. on p. 22).
- [BN05] R. Ball, C. North. “Analysis of user behavior on high-resolution tiled displays.” In: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Vol. 3585 LNCS. 2005, pp. 350–363. ISBN: 3540289437. DOI: [10.1007/11555261\\_30](https://doi.org/10.1007/11555261_30) (cit. on pp. 13, 23).
- [BNB07] R. Ball, C. North, D. a. Bowman. “Move to Improve : Promoting Physical Navigation to Increase User Performance with Large Displays.” In: *Chi Figure 1* (2007), pp. 191–200. DOI: [10.1145/1240624.1240656](https://doi.org/10.1145/1240624.1240656). URL: <http://dl.acm.org/citation.cfm?id=1240656> (cit. on pp. 13, 23).
- [BNC+03] D. A. Bowman, C. North, J. Chen, N. F. Polys, P. S. Pyla, U. Yilmaz. “Information-rich Virtual Environments: Theory, Tools, and Research Agenda.” In: *Proceedings of the ACM Symposium on Virtual Reality Software and Technology. VRST ’03*. Osaka, Japan: ACM, 2003, pp. 81–90. ISBN: 1-58113-569-6. DOI: [10.1145/1008653.1008669](https://doi.org/10.1145/1008653.1008669). URL: <http://doi.acm.org/10.1145/1008653.1008669> (cit. on p. 23).
- [Bro+96] J. Brooke et al. “SUS-A quick and dirty usability scale.” In: *Usability evaluation in industry* 189.194 (1996), pp. 4–7 (cit. on p. 59).
- [BSN06] R. Ball, M. Szwedo, C. North. *Dynamic Size and Speed Cursor for Large , High-Resolution Displays*. Tech. rep. 2006 (cit. on p. 20).
- [CBF14] O. Chapuis, A. Bezerianos, S. Frantzeskakis. “Smarties: an input system for wall display development.” In: *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI ’14* (2014), pp. 2763–2772. DOI: [10.1145/2556288.2556956](https://doi.org/10.1145/2556288.2556956). URL: <https://dl.acm.org/citation.cfm?id=2556956> (cit. on p. 21).
- [CKB08] A. Cockburn, A. Karlson, B. B. Bederson. “A review of overview+detail, zooming, and focus+context interfaces.” In: *ACM Computing Surveys* 41.1 (2008), pp. 1–31. ISSN: 03600300. DOI: [10.1145/1456650.1456652](https://doi.org/10.1145/1456650.1456652). URL: <http://portal.acm.org/citation.cfm?doid=1456650.1456652> (cit. on p. 18).
- [CR05] O. Chapuis, N. Roussel. “Metisse is not a 3D desktop!” In: *Proceedings of the 18th annual ACM symposium on User interface software and technology - UIST ’05* (2005), p. 13. ISSN: 0926-9630. DOI: [10.1145/1095034.1095038](https://doi.org/10.1145/1095034.1095038). URL: <http://portal.acm.org/citation.cfm?doid=1095034.1095038> (cit. on p. 18).

- [CR07] O. Chapuis, N. Roussel. “Copy-and-paste between overlapping windows.” In: *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '07* (2007), p. 201. DOI: [10.1145/1240624.1240657](https://doi.org/10.1145/1240624.1240657). URL: <http://portal.acm.org/citation.cfm?doid=1240624.1240657> (cit. on p. 18).
- [CSR+03] M. Czerwinski, G. Smith, T. Regan, B. Meyers, G. Robertson, G. Starkweather. “Toward Characterizing the Productivity Benefits of Very Large Displays.” In: *Interact 3* (2003), pp. 9–16. URL: <https://www.microsoft.com/en-us/research/publication/toward-characterizing-the-productivity-benefits-of-very-large-displays/> (cit. on pp. 13, 19, 23).
- [CTR02] M. Czerwinski, D. S. Tan, G. G. Robertson. “Women take a wider view.” In: *Proceedings of the SIGCHI conference on Human factors in computing systems Changing our world, changing ourselves - CHI '02 4.4* (2002), p. 195. DOI: [10.1145/503376.503412](https://doi.org/10.1145/503376.503412). URL: <https://dl.acm.org/citation.cfm?id=503412> (cit. on p. 19).
- [DYW+13] W. Dou, L. Yu, X. Wang, Z. Ma, W. Ribarsky. “HierarchicalTopics: Visually exploring large text collections using topic hierarchies.” In: *IEEE Transactions on Visualization and Computer Graphics* 19.12 (2013), pp. 2002–2011. ISSN: 10772626. DOI: [10.1109/TVCG.2013.162](https://doi.org/10.1109/TVCG.2013.162) (cit. on p. 19).
- [EBZ+12] A. Endert, L. Bradel, J. Zeitz, C. Andrews, C. North, V. Tech. “Designing Large High-Resolution Display Workspaces.” In: *AVI '12 Proceedings of the International Working Conference on Advanced Visual Interfaces* (2012), pp. 58–65. DOI: [10.1145/2254556.2254570](https://doi.org/10.1145/2254556.2254570). URL: <https://dl.acm.org/citation.cfm?id=2254570> (cit. on p. 21).
- [GCG+17] C. Gutwin, A. Cockburn, N. Gough, C. Science, S. Engineering, N. Zealand. “A Field Experiment of Spatially-Stable Overviews for Document Navigation.” In: (2017). DOI: [10.1145/3025453.3025905](https://doi.org/10.1145/3025453.3025905) (cit. on p. 17).
- [GG98] C. Gutwin, S. Greenberg. “Design for individuals, design for groups.” In: *Proceedings of the 1998 ACM conference on Computer supported cooperative work - CSCW '98* (1998), pp. 207–216. DOI: [10.1145/289444.289495](https://doi.org/10.1145/289444.289495). URL: <http://portal.acm.org/citation.cfm?doid=289444.289495> (cit. on p. 22).
- [Goy13] N. Goyal. “Effects of Visualization and Note - Taking on Sensemaking and Analysis.” In: *SIGCHI - Conference on Human Factors in Computing Systems* (2013), pp. 2721–2724. DOI: [10.1145/2470654.2481376](https://doi.org/10.1145/2470654.2481376) (cit. on p. 55).

- [GSW01] F. Guimbretière, M. Stone, T. Winograd. “Fluid Interaction with High-resolution Wall-size Displays.” In: *Proceedings of the 14th Symposium on User Interface Software and Technology (UIST’01)* 3.2 (2001), pp. 21–30. DOI: [10.1145/502348.502353](https://doi.org/10.1145/502348.502353). URL: <http://doi.acm.org/10.1145/502348.502353> (cit. on p. 20).
- [Har06] S. G. Hart. “Nasa-Task Load Index (NASA-TLX); 20 Years Later.” In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50.9 (2006), pp. 904–908. DOI: [10.1177/154193120605000909](https://doi.org/10.1177/154193120605000909). eprint: <https://doi.org/10.1177/154193120605000909>. URL: <https://doi.org/10.1177/154193120605000909> (cit. on p. 59).
- [HD06] K. Halskov, P. Dalsgård. “Inspiration card workshops.” In: *Proceedings of the 6th conference on Designing Interactive systems* (2006), pp. 2–11. DOI: [10.1145/1142405.1142409](https://doi.org/10.1145/1142405.1142409). URL: <http://portal.acm.org/citation.cfm?doid=1142405.1142409> (cit. on p. 22).
- [HF01] K. Hornbæk, E. Frøkjær. “Reading of electronic documents: the usability of linear, fisheye, and overview+ detail interfaces.” In: *Proceedings of the SIGCHI conference on* (2001), pp. 293–300. DOI: [10.1145/365024.365118](https://doi.org/10.1145/365024.365118). URL: <http://dl.acm.org/citation.cfm?id=365118> (cit. on p. 18).
- [HMRS06] E. M. Huang, E. D. Mynatt, D. M. Russell, A. E. Sue. “Secrets to Success and Fatal Flaws: The Design of Large-Display Groupware.” In: *IEEE Comput. Graph. Appl.* 26.1 (Jan. 2006), pp. 37–45. ISSN: 0272-1716. DOI: [10.1109/MCG.2006.21](https://doi.org/10.1109/MCG.2006.21). URL: <http://dx.doi.org/10.1109/MCG.2006.21> (cit. on p. 21).
- [HS88] S. G. Hart, L. E. Staveland. “Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research.” In: *Human Mental Workload*. Ed. by P. A. Hancock, N. Meshkati. Vol. 52. Advances in Psychology Supplement C. North-Holland, 1988, pp. 139–183. DOI: [10.1016/S0166-4115\(08\)62386-9](https://doi.org/10.1016/S0166-4115(08)62386-9). URL: <http://www.sciencedirect.com/science/article/pii/S0166411508623869> (cit. on p. 59).
- [HSM+04] D. R. Hutchings, G. Smith, B. Meyers, M. Czerwinski, G. Robertson. “Display Space Usage and Window Management Operation Comparisons between Single Monitor and Multiple Monitor Users.” In: *Proceedings of the Working Conference on Advanced Visual Interfaces (AVI’04)* (2004), pp. 32–39. DOI: [10.1145/989863.989867](https://doi.org/10.1145/989863.989867). URL: <https://dl.acm.org/citation.cfm?id=989867> (cit. on p. 18).
- [Inc06] A. S. Incorporated. *PDF Reference*. Tech. rep. 2006. URL: [http://www.adobe.com/content/dam/acom/en/devnet/acrobat/pdfs/pdf\\_reference\\_1-7.pdf](http://www.adobe.com/content/dam/acom/en/devnet/acrobat/pdfs/pdf_reference_1-7.pdf) (cit. on p. 41).

- [JFW02] B. Johanson, A. Fox, T. Winograd. “The Interactive Workspaces Project: Experiences with Ubiquitous Computing Rooms.” In: *IEEE Pervasive Computing* 1.2 (Apr. 2002), pp. 67–74. ISSN: 1536-1268. DOI: [10.1109/MPRV.2002.1012339](https://doi.org/10.1109/MPRV.2002.1012339). URL: <http://dx.doi.org/10.1109/MPRV.2002.1012339> (cit. on p. 21).
- [JH14] M. R. Jakobsen, K. Hornbaek. “Up close and personal: Collaborative work on a high-resolution multitouch wall display.” In: *ACM Transactions on Computer-Human Interaction* 21.2 (2014), pp. 1–34. ISSN: 10730516. DOI: [10.1145/2576099](https://doi.org/10.1145/2576099). URL: <http://dl.acm.org/citation.cfm?id=2592268.2576099> (cit. on p. 22).
- [KJH12] S. Knudsen, M. R. Jakobsen, K. Hornbæk. “An Exploratory Study of How Abundant Display Space May Support Data Analysis.” In: *Proceedings of the 7th Nordic Conference on Human-Computer Interaction Making Sense Through Design - NordiCHI '12* (2012), pp. 558–567. DOI: [10.1145/2399016.2399102](https://doi.org/10.1145/2399016.2399102). URL: <http://dl.acm.org/citation.cfm?doid=2399016.2399102> (cit. on pp. 14, 22, 23, 25).
- [KJW+14] S. Koch, M. John, M. Worner, A. Muller, T. Ertl. “VarifocalReader &#x2014; In-Depth Visual Analysis of Large Text Documents.” In: *IEEE Transactions on Visualization and Computer Graphics* 20.12 (2014), pp. 1723–1732. ISSN: 1077-2626. DOI: [10.1109/TVCG.2014.2346677](https://doi.org/10.1109/TVCG.2014.2346677). URL: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6875959> (cit. on p. 19).
- [LCB+14] C. Liu, O. Chapuis, M. Beaudouin-Lafon, E. Lecolinet, W. E. Mackay. “Effects of display size and navigation type on a classification task.” In: *the 32nd annual ACM conference* (2014), pp. 4147–4156. DOI: [10.1145/2556288.2557020](https://doi.org/10.1145/2556288.2557020). URL: <https://dl.acm.org/citation.cfm?id=2557020> (cit. on pp. 13, 23).
- [LCBL17] C. Liu, O. Chapuis, M. Beaudouin-Lafon, E. Lecolinet. “CoReach.” In: *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17* (2017), pp. 6730–6741. DOI: [10.1145/3025453.3025594](https://doi.org/10.1145/3025453.3025594). URL: <http://dl.acm.org/citation.cfm?doid=3025453.3025594> (cit. on p. 20).
- [LHK+17] L. Lischke, J. Hoffmann, R. Krüger, P. Wozniak, A. Schmidt. “Towards Efficient Interaction Techniques for Social Media Data Exploration on Large High-Resolution Displays.” In: (2017) (cit. on p. 20).
- [LKK15] L. Lischke, P. Knierim, H. Klink. “Mid-Air Gestures for Window Management on Large Displays.” In: *Tagungsband der Mensch und Computer (MuC'15)* (2015), pp. 439–442. DOI: [10.1515/9783110443929-072](https://doi.org/10.1515/9783110443929-072) (cit. on p. 21).



- [LMW+15] L. Lischke, S. Mayer, K. Wolf, N. Henze, A. Schmidt, S. Leifert, H. Reiterer. “Using Space.” In: *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '15* (2015), pp. 1845–1850. DOI: [10.1145/2702613.2732845](https://doi.org/10.1145/2702613.2732845). URL: <http://dl.acm.org/citation.cfm?id=2702613.2732845> (cit. on p. 23).
- [LMW+16] L. Lischke, S. Mayer, K. Wolf, N. Henze, H. Reiterer, A. Schmidt. “Screen arrangements and interaction areas for large display work places.” In: *Proceedings of the 5th ACM International Symposium on Pervasive Displays - PerDis '16* (2016), pp. 228–234. DOI: [10.1145/2914920.2915027](https://doi.org/10.1145/2914920.2915027). URL: <http://dl.acm.org/citation.cfm?doid=2914920.2915027> (cit. on p. 22).
- [LSF+16] L. Lischke, V. Schwind, K. Friedrich, A. Schmidt, N. Henze. “MAGIC-Pointing on Large High-Resolution Displays.” In: *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (2016), pp. 1706–1712. DOI: [10.1145/2851581.2892479](https://doi.org/10.1145/2851581.2892479). URL: <http://doi.acm.org/10.1145/2851581.2892479> (cit. on p. 21).
- [MRB05] S. Malik, A. Ranjan, R. Balakrishnan. “Interacting with large displays from a distance with vision-tracked multi-finger gestural input.” In: *Proceedings of the 18th annual ACM symposium on User interface software and technology - UIST '05* (2005), p. 43. DOI: [10.1145/1095034.1095042](https://doi.org/10.1145/1095034.1095042). URL: <http://portal.acm.org/citation.cfm?doid=1095034.1095042> (cit. on p. 20).
- [MTB+17] N. Maudet, P. Tchernavskij, M. Beaudouin-lafon, W. E. Mackay, U. Paris-saclay, F.-. Orsay. “Beyond Grids : Interactive Graphical Substrates to Structure Digital Layout.” In: (2017) (cit. on p. 18).
- [NAS08] J. Novak, M. Aggeler, G. Schwabe. “Designing large-display workspaces for cooperative travel consultancy.” In: *Proceeding of the twenty-sixth annual CHI conference extended abstracts on Human factors in computing systems - CHI '08* (2008), p. 2877. DOI: [10.1145/1358628.1358777](https://doi.org/10.1145/1358628.1358777). URL: <http://portal.acm.org/citation.cfm?doid=1358628.1358777> (cit. on p. 22).
- [NBC06] T. Ni, D. A. Bowman, J. Chen. “Increased Display Size and Resolution Improve Task Performance in Information-Rich Virtual Environments.” In: *Proceedings of Graphics Interface 2006* (2006), pp. 139–146. ISSN: 0713-5424. URL: <http://dl.acm.org/citation.cfm?id=1143079.1143102> (cit. on pp. 13, 23).
- [OSB99] K. O'Hara, A. Sellen, R. Bentley. “Supporting memory for spatial location while reading from small displays.” In: *CHI '99: CHI '99 extended abstracts on Human factors in computing systems* (1999), pp. 220–221. DOI: [10.1145/321855.321856](https://doi.org/10.1145/321855.321856).



- 1145/632716.632853. URL: <https://dl.acm.org/citation.cfm?id=632853> (cit. on p. 19).
- [PC05] P. Pirolli, S. Card. “The sensemaking process and leverage points for analyst technology as identified through cognitive task analysis.” In: *Proceedings of international conference on intelligence analysis*. Vol. 5. 2005, pp. 2–4 (cit. on p. 55).
- [PNB09] S.M. Peck, C. North, D. Bowman. “A multiscale interaction technique for large, high-resolution displays.” In: *3DUI - IEEE Symposium on 3D User Interfaces 2009 - Proceedings* (2009), pp. 31–38. DOI: [10.1109/3DUI.2009.4811202](https://doi.org/10.1109/3DUI.2009.4811202) (cit. on p. 21).
- [RCL+98] G. Robertson, M. Czerwinski, K. Larson, D.C. Robbins, D. Thiel, M. van Dantzich. “Data mountain.” In: *Proceedings of the 11th annual ACM symposium on User interface software and technology - UIST '98* (1998), pp. 153–162. DOI: [10.1145/288392.288596](https://doi.org/10.1145/288392.288596). URL: <https://dl.acm.org/citation.cfm?id=288596> (cit. on p. 17).
- [RDS02] D.M. Russell, C. Drews, A. Sue. “Social Aspects of Using Large Public Interactive Displays for Collaboration.” In: *UbiComp 2002: Ubiquitous Computing: 4th International Conference Göteborg, Sweden, September 29 – October 1, 2002 Proceedings*. Ed. by G. Borriello, L.E. Holmquist. Berlin, Heidelberg: Springer Berlin Heidelberg, 2002, pp. 229–236. ISBN: 978-3-540-45809-8. DOI: [10.1007/3-540-45809-3\\_18](https://doi.org/10.1007/3-540-45809-3_18). URL: <https://link.springer.com/book/10.1007/3-540-45809-3#page=244> (cit. on p. 22).
- [STB07] G. Shoemaker, A. Tang, K. S. Booth. “Shadow reaching.” In: *Proceedings of the 20th annual ACM symposium on User interface software and technology - UIST '07* (2007), p. 53. DOI: [10.1145/1294211.1294221](https://doi.org/10.1145/1294211.1294221). URL: <http://portal.acm.org/citation.cfm?doid=1294211.1294221> (cit. on p. 20).
- [TC03] D. Tan, M. Czerwinski. “Effects of Visual Separation and Physical Discontinuities when Distributing Information across Multiple Displays.” In: *Proceedings Interact'03* (2003), pp. 252–259. URL: <https://www.microsoft.com/en-us/research/publication/effects-of-visual-separation-and-physical-discontinuities-when-distributing-information-across-multiple-displays> (cit. on p. 19).
- [TGSP03] D. S. Tan, D. Gergle, P. Scupelli, R. Pausch. “With similar visual angles, larger displays improve spatial performance.” In: *Proceedings of the conference on Human factors in computing systems - CHI '03* 5 (2003), p. 217. DOI: [10.1145/642647.642650](https://doi.org/10.1145/642647.642650). URL: <http://portal.acm.org/citation.cfm?doid=642611.642650> (cit. on pp. 13, 23).

- [TLGF09] A. Tang, J. Lanir, S. Greenberg, S. Fels. “Supporting transitions in work.” In: *Proceedings of the ACM 2009 international conference on Supporting group work GROUP 09* (2009), p. 149. DOI: [10.1145/1531674.1531697](https://doi.org/10.1145/1531674.1531697). URL: <http://portal.acm.org/citation.cfm?doid=1531674.1531697> (cit. on p. 22).
- [TPZM04] E. Taft, J. Pravetz, S. Zilles, L. Masinter. *The application/pdf media type*. Tech. rep. 2004. URL: <https://tools.ietf.org/html/rfc3778> (cit. on p. 41).
- [UGC17] M. S. Uddin, C. Gutwin, A. Cockburn. “The Effects of Artificial Landmarks on Learning and Performance in Spatial-Memory Interfaces.” In: *CHI ’17: Proceedings of the 2017 SIGCHI Conference on Human Factors in Computing Systems* (2017), To appear. DOI: [10.1145/3025453.3025497](https://doi.org/10.1145/3025453.3025497). URL: <https://dl.acm.org/citation.cfm?id=3025497> (cit. on p. 18).
- [WCR+11] J. Walny, S. Carpendale, N. H. Riche, G. Venolia, P. Fawcett. “Visual Thinking In Action: Visualisations As Used On Whiteboards.” In: *CHI ’11* (2011), pp. 2508–2517. URL: <http://research.microsoft.com/pubs/179625/Walny2011InfoVis.pdf> (cit. on p. 22).
- [WGSS11] M. Waldner, R. Grasset, M. Steinberger, D. Schmalstieg. “Display-adaptive window management for irregular surfaces.” In: *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces (ITS ’11)* (2011), pp. 222–231. DOI: [10.1145/2076354.2076394](https://doi.org/10.1145/2076354.2076394). URL: <http://dl.acm.org/citation.cfm?doid=2076354.2076394> (cit. on p. 18).
- [WKL+16] N. Wozniak Paweł and Goyal, P. Kucharski, L. Lischke, S. Mayer, M. Fjeld. “RAMPARTS: Supporting Sensemaking with Spatially-Aware Mobile Interactions.” In: *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. CHI ’16. San Jose, California, USA: ACM, 2016, pp. 2447–2460. ISBN: 978-1-4503-3362-7. DOI: [10.1145/2858036.2858491](https://doi.org/10.1145/2858036.2858491). URL: <http://doi.acm.org/10.1145/2858036.2858491> (cit. on pp. 14, 55).
- [WVL14] J. R. Wallace, D. Vogel, E. Lank. “Effect of Bezel Presence and Width on Visual Search.” In: *Proceedings of The International Symposium on Pervasive Displays (PerDis’14)* (2014), pp. 118–123. ISSN: 07135424. DOI: [10.1145/2611009.2611019](https://doi.org/10.1145/2611009.2611019). URL: <http://doi.acm.org/10.1145/2611009.2611019> (cit. on p. 19).
- [YCNF10] S. Yang, H. Chung, C. North, E. A. Fox. “The Effect of Presenting Long Documents with Large High- Resolution Displays on Comprehension of Content and User Experience.” In: (2010), pp. 1–17 (cit. on p. 21).

[YHN07] B. Yost, Y. Haciahetoglu, C. North. “Beyond visual acuity.” In: *the SIGCHI conference* (2007), pp. 101–110. ISSN: 1595935932. DOI: [10.1145 / 1240624.1240639](https://doi.org/10.1145/1240624.1240639). URL: <https://dl.acm.org/citation.cfm?id=1240639> (cit. on p. 19).

All links were last followed on October 31, 2017.



## **Declaration**

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

---

place, date, signature