# ENABLING AND INFORMING THE DESIGN OF CROSS-MEDIA PERSONAL INFORMATION MANAGEMENT SOLUTIONS

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# ABSTRACT

A significant amount of personal information is received, stored and reused on a daily basis. Although we organise our information in various ways, we frequently face problems in re-finding information at a later point in time. The problem of organising and re-finding information is addressed by multi-disciplinary research in the field of Personal Information Management (PIM). While various tools for PIM activities, such as file explorers or cloud-based services, exist for a long time, they introduced the problem that information becomes fragmented across these tools. Further, we still often use digital and physical media in a simultaneous way during everyday tasks. Nevertheless, existing research has mainly focussed on the design of PIM tools for either the digital or physical information space, often neglecting the simultaneous use of digital and physical documents.

In this dissertation, we take a cross-media approach to PIM application design where the digital and physical information spaces are unified. We introduce the vision of *Cross-Media PIM User Interfaces* which foresee a seamless transition across both information spaces during re-finding activities. Additionally, we aim for synergy between user interface design and a user's current organisational behaviour and re-finding strategies. In order to enable the design of cross-media PIM user interfaces, we have defined a number of user-centric as well as technical requirements. These requirements are based on our gained insights into a user's organisational and re-finding behaviour as well as the design of prosthetic memory helping users during their re-finding activities. In a second phase, we have developed the Document Tracking (DocTr), Context Modelling Toolkit (CMT) and User Interface Management (UIM) software frameworks to track, manage and display the necessary document metadata and the corresponding organisational structures. This metadata is needed to offer support for the re-finding mechanisms of a user's organic memory. The UIM framework is also responsible for the seamless transition between the digital and physical information spaces. The presented software frameworks enabled the design of different cross-

media PIM user interfaces such as the PimVis visualisation that can interact with the file explorer and augmented ring binders as well as an augmented physical filing cabinet which can be controlled via a tangible user interface. Our proof-of-concept user interfaces have been used as study platform in two exploratory user studies. The results of these studies validate our three proposed main design principles including the support for a seamless transition between information spaces and the synergy with a user's current organisational behaviour as well as the re-finding mechanisms of the organic memory. We also gained further insights into the design space of cross-media PIM user interfaces where we show that users use different re-finding cues across the digital and physical information space, that user interfaces are best integrated in a ubiquitous way in a user's organisational environment and that users aim to be in control of the integration of the user interfaces in their environment where self-development of the interactions between the user interfaces is crucial. This dissertation presents the foundations for a new generation of PIM solutions that work in synergy with the user and brings up some essential design questions for future cross-media PIM solutions. Finally, the developed software platforms have various valorisation opportunities. For example, the DocTr platform, which can determine when digital and paper documents have been used and where they are located, can also be very useful as a tool in libraries or large companies where document management is regulated by compliance standards. On the other hand, the CMT platform, which finds out which documents were used during a specific task, can also be used to allow the user to program their smart home. This versatile applicability of the individual software platforms bring a valuable extra dimension to the outcome of this dissertation.

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# CONTENTS

# 1

# INTRODUCTION

In our daily life, we encounter large amounts of information that we want to keep in memory. However, our organic memory is fallible. When people "store" information in their organic memory, the information is abstracted to concepts and these new concepts are associated with previously gained knowledge. The relationships between concepts in our organic memory each have their own amount of energy as given by the Spreading Activation Theory by Collins and Loftus [25]. The more we use a specific relationship between concepts the stronger the energy of the particular relationship becomes. During the recall process, the strongest relationships are activated [3]. Therefore, when concepts and relationships are not triggered regularly, their energy is too low to be activated during recall. This is often the cause of forgetting information or leads to the case where people only recall main concepts but no details. Due to the fallibility of our organic memory, we started to use prosthetic memories (PMs) a long time ago. Prosthetic memories can be artefacts such as the well-known post-it notes or applications such as OneNote[1] which help us to recall possibly forgotten information.

## 1.1 PROSTHETIC MEMORIES IN THE WILD

Prosthetic memories using paper such as post-it notes, photobooks or birthday calendars as an artefact are well-used. During the past decades, these paper-based prosthetic memories have often found a digital implementation where extra digital functionality is given to the user. For example, Evernote[2] and OneNote digitised the idea of post-it notes,

1 `http://www.onenote.com`
2 `http://evernote.com`

Flickr[3] and Instagram[4] introduced digital photobooks in a social media context and digital calendars are integrated in every smartphone operating system such as Android or email applications. Prosthetic memories can be used for different purposes including reflection, re-visitation, reminding and recall. The photobook paradigm is one of the most common prosthetic memory design with a reflection and re-visitation purpose. Besides the use of digital photobook tools such as PhotoDirector[5] to store personal photos, people also use social media platforms such as Facebook[6] to keep a personal archive [127]. However, personal archives become large since nowadays it is easy to capture everything and photos are often spread over different devices or services. Consequently, users have a hard time to re-find their photos for reflection [118]. Therefore, various researchers explored the design of so called slow technologies for reflection [45]. Slow technologies do not require particular user interactions and are often ubiquitously integrated into a user's digital and physical environment. For example, Facebook integrated the slow technology approach by giving users a reminder post on the Facebook wall which tells them that a certain picture is taken some years ago as shown in Figure 1.1. In this way, a user is given the opportunity to reflect about a past event without the effort of browsing their photo collections.

Prosthetic memories are often also designed for recalling information during knowledge tasks performed after meetings or lectures. For example, the Ferret browser [117] allows users to browse meeting data such as video recordings or transcripts and provides communication channels to indicate which person has said what. Since meetings are a collaborative activity, the Collaborative Recorded Meeting application integrates the sharing of notes and allows users to browse the meeting recordings by recommendations of other participants [83]. Finally, in the context of lectures, treemaps can be used to visualise the transcript of the recorded voices in order to facilitate navigation activities through recorded audio fragments [82].

We can observe a significant amount of research on the design of prosthetic memories in various settings and with different purposes. In this dissertation, we will focus on the design of prosthetic memories

3 http://www.flickr.com
4 http://www.instagram.com
5 http://www.cyberlink.com
6 http://www.facebook.com

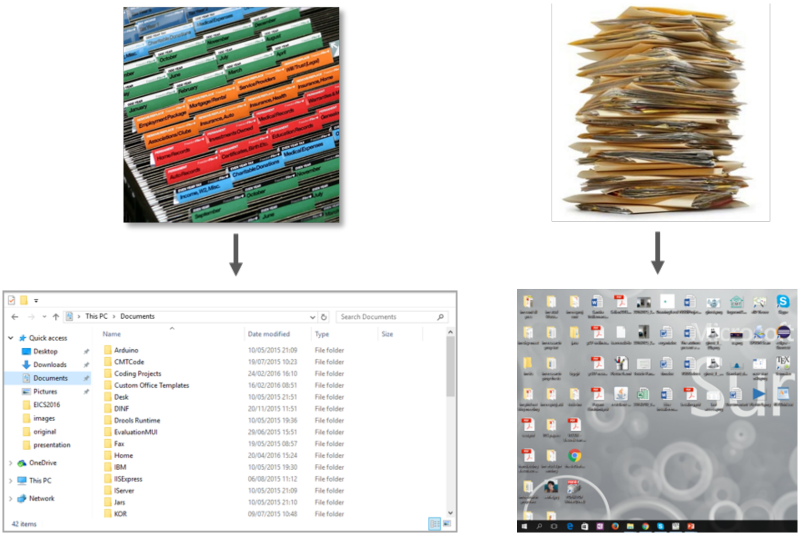

Figure 1.1.: Slow technology for reflection integrated in Facebook

with the purpose for recall in the research field of Personal Information Management (PIM). The main focus of the PIM research field lies in investigating how and why people keep, manage and re-find personal information in the digital and physical information space [56]. These insights are commonly used to design PIM tools which try to overcome the observed document organisation and re-finding issues.

## 1.2 PERSONAL INFORMATION MANAGEMENT

A pioneer in investigating how people organise physical documents is Malone [79]. In his research he observed the use of the two main organisational strategies. Filing takes place when documents are given a label and are ordered in a specific way (e.g. alphabetically). In contrast, piling is the act of creating piles of unlabelled documents. Filing documents away costs time and effort due to the labelling and classification in a new or existing filing structure [24]. We can observe the filing strategy in, for example, an alphabetically ordered filing cabinet. In contrast, the formation of piles does not require this effort. However, since piles lack labels and a specific order, re-finding becomes harder when the piles grow or time elapses [79]. Both organisational strategies have been taken over in the design of the classical digital desktop environment which we still heavily use today. The typical folder hierarchy of the Windows File Explorer or MacOS Finder is metaphorically inspired by the filing cabinet as illustrated in Figure 1.2a. Similarly, the piling organisational structure found its digital implementation in the desktop interface where documents can just be placed randomly without the need to fit into a hierarchical structure as illustrated in Figure 1.2b. This interface metaphor has been introduced with the idea that it is easier for novel users to use new technology in a way familiar to their current organisational behaviour. However, various researchers argue for a more suitable approach for organising digital media. For example, Bush [17] argued to enable users to explicitly create associations between information items as a metaphor to the way our organic memory stores information. Although this vision has been significantly investigated, more recent research shows that users are not eager to change their current organisational behaviour [23].

People organise their personal information in order to re-find it when time elapses. However, both, filing and piling, organisational strategies in the digital and physical information spaces do not perfectly fit the re-finding strategies of users which often leads to inefficient or unsuccessful retrieval of needed digital and physical documents. The main reason for this conflict between organisational and re-finding strategies is the loss of the documents' contextual metadata (e.g. when and in which tasks they have been used) when they are organised. Users try to overcome this loss of contextual metadata by, for example, creating long and complex labels for digital documents and structuring their folder hierarchies in terms of projects or tasks [58]. Therefore, folder structures can become broad or deep. Consequently, users cannot remember the cognitive schema of their overall folder hierarchies any more [15, 6]. On the other hand, pile structures preserve better a document's contextual metadata than files. They are often composed out of documents which have a contextual relationship with each other [92]. In addition, piles have more spatial reference points than documents hidden in a filing cabinet which is an extra help during re-finding activities. However, users commonly forget the details of a pile's surrounding context when time elapses. They have to fall back on the pile's spatial references in order to trigger the organic



(a) Filing (b) Piling

Figure 1.2.: Organisational strategies transferred to the digital space

memory when re-finding a document [57]. Finally, since piles often consist of chronologically stacked documents, they have an advantage over filing structures in the context of re-finding based on temporally related memory cues [92].

Besides the conflict between the organisational and re-finding strategies, a second major issue is the fragmentation problem. In the current digital era, one may have different devices, cloud services such as Mircosoft OneDrive[7] or Google Drive[8] and accounts on various social media websites where personal information is stored and shared. Re-finding documents in such a fragmented information environment implies additional cognitive effort [110]. Before users actually can start their search, they have to first recall on which device or cloud service they have stored the needed document. It is known that recalling is much harder than using recognition (i.e. search based on browsing content) which is done when searching within an organisational structure such as the File Ex-

7 http://onedrive.live.com
8 http://www.google.com/drive

plorer [108, 98]. A second issue concerning the fragmentation is that users apply a different schema of organisational structures across applications [11]. For example, the folder hierarchies constructed within the user's email application, their File Explorer and bookmarks can look quite different. This inconsistency across organisational structures again impose extra cognitive effort during tasks where information is required which is stored in different tools and devices. In order to overcome the above-mentioned re-finding issues, researchers have designed a wide range of prosthetic memories. These prosthetic memories can take the form of a digital application for re-finding digital documents or the physical space can be augmented with digital functionality to help users re-finding their physical documents.

### 1.2.1 *Prosthetic Memories for Digital Media*

The most common prosthetic memory for digital media is the search functionality which is commonly by default integrated in operating systems such as Windows and MacOS. However, the use of search is often not the best way to retrieve a digital document since users have to remember (parts) of the document's label or keywords included in the content of the document which can be a burden when time elapses [98]. In addition, by representing search results in a simple list view, the context metadata of a document is totally lost. Therefore, various alternatives to the search paradigm have been investigated. A well-known alternative is tagging where users can add multiple tags to documents and retrieve them by browsing or querying the tag set. Nevertheless, recent work indicates that due to the extra effort of creating tags and the time consumption for allocating tags to a document, a majority of users still prefer the commonly used folder hierarchies [23].

Besides search and the alternative interaction techniques for organising documents, significant research is directed to the issue of document fragmentation. These so-called unifying PIM systems are often designed as a central repository which includes all digital documents of a user. Three main paradigms can be observed regarding the interaction with such unifying PIM solutions. A first body of related work is focussed on the creation of associations between documents instead of forcing the user to categorise documents in a hierarchical way. This vision was first introduced by Vannevar Bush in 1945 [17]. In the following decades, his vision formed the foundations for hypertext as used on the World Wide Web as well as has been implemented in a wide range of PIM applications. While in the first systems such as in the Semantic File System application [42] users had to manually create the associations between documents, more recent tools investigate the partially automatic instantiation of associations as, for example, realised in HayStack [62]. A second approach is to categorise documents by the tasks in which they have been used. This *Task Information Management (TIM)* approach has been inspired by the idea that documents belong to a specific task and have a certain importance within a particular task [20]. Systems such as the extended OntoPIM application [63] try to foresee the user with the most relevant documents for their task at hand. Finally, documents from the central repository can also be given to the user in a timeline-based design. In the context of PIM, the vision of lifelogging applications is to gather all the interactions with documents and allow users to re-find documents based on temporal related queries. The results of these queries can be displayed to the user by, for example, representing them in the form of chronologically ordered arrays as realised in LifeStreams [36]. Although the vision behind the above-mentioned unification systems is promising, they do not integrate physical documents such as printed paper documents or loose notes. However, most information spaces of users still contain of a significant amount of physical documents [92, 119]. Additionally, it has been shown that users still prefer to use their current tools and strategies for organising their digital and physical documents [12].

### 1.2.2 *Paper Documents and Their Prosthetic Memory*

Despite the digital revolution, paper-based notes are still a commonly used prosthetic memory. A major disadvantage of notes is that they might become inadequate for the retrieval of detailed information after some time [120]. In order to overcome this issue, applications have been designed which augment paper notes with audio recordings. Users can jump to relevant audio fragments by selecting a part of the note [97, 124]. These interactions are enabled by smartpen technologies such as such as the Digital Pen by Anoto[9] used in commercial available smartpens such

9 `http://www.anoto.com`

as the ones of LiveScribe[10]. The Digital Pen technology uses a dotted pattern which is printed on the paper sheet and can be recognised by the pen to determine the pen's position. Recently, smartpens also found their way into commercially available educational games such as the TipToi[11] interactive books.

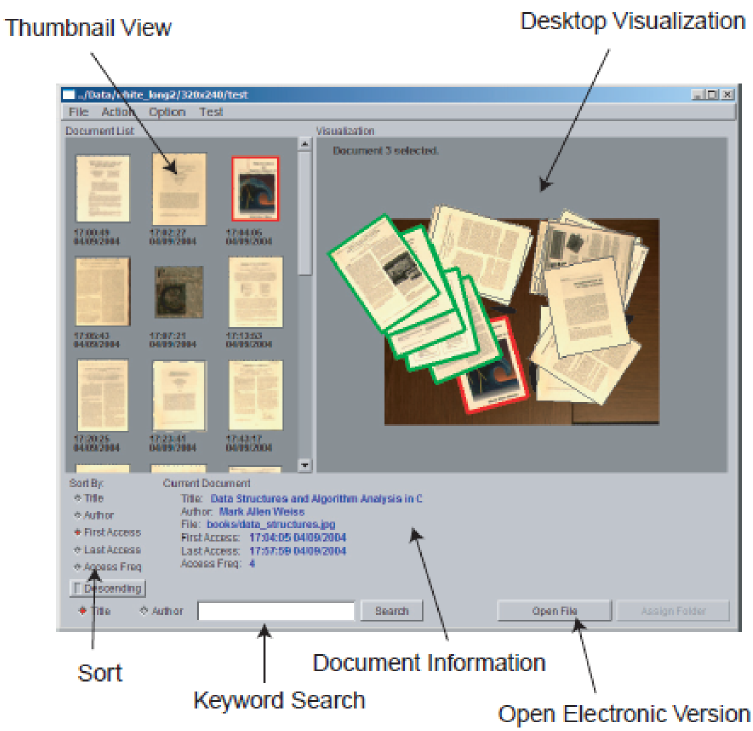


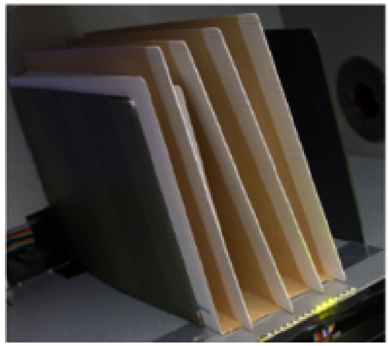

Figure 1.3.: A video-based approach to track pile interactions [67]

In the context of PIM, current research mainly focusses on enabling the positional tracking of physical documents and their organisational structures. For example, the work of Kim et al. [67] tracks the interactions with a physical pile by using advanced image recognition techniques and gives users the opportunity to digitally browse through the pile and provides users with a general overview of the tracked documents in

10 http://www.livescribe.com
11 http://www.tiptoi.com

a thumbnail view as shows in Figure 1.3. However, most applications are directed to one specific setting such as tracking interactions with documents in a physical pile. In addition, the graphical user interface which allows users to digitally search for paper documents and the integration with the digital information space are often limited.

(a) Electronic circuits



(b) LED user interface

Figure 1.4.: The bookshelves and folders of the SOPHYA framework [51]

Besides the tracking of individual physical documents, some applications focus on how to track storage artefacts such as physical folders as realised in the SOPHYA framework [51] where physical folders and the bookshelves are augmented with electronic circuits as illustrated in Figure 1.4a. These electronic circuits notify the application about which folder has been placed at which particular spot in the bookshelf. Additionally, LEDs are attached to the front edge of the bookshelf in order to show the user the folder in which the searched document is stored as shown in Figure 1.4b. Although such applications provide some physical feedback about the position of the needed document (e.g. by highlighting the LED), the integration with digital documents as well as the design of prosthetic memories using the tracked metadata remains limited. There are major opportunities to investigate the design of advanced graphical and tangible user interfaces which include digital as well as physical documents simultaneously and are in line with the user's existing organisational behaviour.

## 1.3 RESEARCH QUESTIONS

Over the past decades we have witnessed the development of a wide range of prosthetic memory applications supporting PIM activities with regard to digital media. Besides the design of novel visualisation techniques, some of these applications try to overcome the information fragmentation across digital tools and cloud services by means of a central repository for a user's digital documents. However, we keep on using digital and physical documents in a simultaneous way during daily tasks [92, 119]. It has further been shown that frequent tablet users often print digital documents in order to facilitate the task at hand [18]. Recent studies highlight that besides the personal preferences for physical documents, companies in various business sectors do not get rid of physical documents due to productivity or law reasons [53]. Although we use them together during tasks, they each have their own information space with its particular affordances. Consequently, we have to organise digital and physical documents in the digital and physical information space. Research related to the design of prosthetic memories for the physical information space is mainly focussed on enabling the tracking of physical documents and their organisational structures. These applications do not foresee the unification with a user's digital information space. Similarly, advanced prosthetic memories for digital media do not integrate physical documents. The resulting cross-media information fragmentation leads to significant cognitive effort during re-finding activities since users have to switch between not only the information spaces but also between the schemas of the constructed organisational structures (e.g. from the physical filing cabinet schema to the File Explorer schema). We can conclude that there is a lack of research on solutions which help users during re-finding activities across information spaces in a way that the transition between the information spaces happens seamlessly. Therefore, we can formulate the following main dissertation problem statement.

**Main Problem Statement.** *While knowledge workers organise digital and physical documents in their own information space, existing prosthetic memories which support users during re-finding activities lack re-finding support for this fragmented cross-media environment, leading to inevitable cognitive effort during re-finding tasks.*

In this dissertation, we propose the design of so-called *cross-media PIM user interfaces* as a solution for the given problem statement. Cross-media PIM user interfaces should provide a seamless transition between the digital and physical information spaces during the re-finding of digital as well as physical documents. It is the overall goal of a cross-media PIM user interface to decrease the cognitive effort which exists when users have to switch between the digital and physical information spaces during a re-finding activity. We can define the following main research question for the presented dissertation.

**Main Research Question.** *How can we enable and inform the design of cross-media PIM user interfaces supporting a seamless transition between the digital and physical information space during re-finding activities?*

In order to answer the main research question, we defined three research questions where the results of each research question contribute to the overall solution. In a first phase of the presented dissertation, we investigated the design foundations for our envisioned cross-media PIM user interfaces by first gaining in depth insights into the user's cross-media PIM behaviour. Our previous work has given us insights into the relations between the used organisational structures and the applied re-finding mechanisms. In this dissertation we build upon this knowledge where we further explored opportunities for the design of prosthetic memories which try to overcome the user's experienced re-finding issues. In this first phase, the following research question will be answered.

**Research Question 1** (RQ1). *What are the main design requirements for the design of the envisioned cross-media PIM user interfaces?*

In order to enable the design of cross-media PIM user interfaces, we have to investigate how we can track, centrally store and display the needed metadata of digital and physical documents. In addition, the tracking of documents and their organisational structures as well as the metadata should be done in a generic and extensible way. The extensibility is required due to the fact that users might have significantly different cross-media PIM behaviour. Additionally, we aim to design a sustainable PIM solution that can be used and extended to explore the design of advanced future PIM solutions and offers various valorisation opportunities. We can formulate the following research question.

**Research Question 2** (RQ2). *How can we enable the tracking, storage and visualisation of metadata for digital and physical documents and organisational structures, defined by the design requirements, in a generic and extensible way?*

In the last phase of the presented dissertation, we explored how we can inform the design space of the enabled cross-media PIM user interfaces. Moreover, we can formulate the following research question regarding the exploration of the design space for cross-media PIM user interfaces.

**Research Question 3** (RQ3). *How can we design cross-media PIM user interfaces based on the defined design requirements and what are generic design implications for these user interfaces?*

The dissertation provides in depth insights into the given research questions by elaborating on the results of the individual research questions. Finally, we place our findings against the body of related work in the discussion section in order to position the scientific contribution of the presented dissertation.

### 1.3.1 *Methodology*

In order to answer the aforementioned research questions, we have applied the *Research through Design* (RtD) [128] methodology. The RtD methodology is often used in innovation where technology is designed with the purpose to illustrate how the future can or should look alike. More important is that the outcome of this research method is a set of design guidelines and implications as well as future research questions. This is in contrast to design methodologies in Human-Computer Interaction (HCI) such as User-centric Design and System-centric Design where systems are designed to fulfil well-defined user or technical needs and where the outcome often consists of usability or technical evaluations to verify how well these needs are accomplished.

The RtD methodology includes three main steps. We first have to gain insights in the unit of analysis including the problem statement and the user's behaviour. Second, innovative technology is designed and implemented. In a third phase, the developed technology is used to gain more insights in various aspects of the unit of analysis. For example, the research results can be initial design implications, a design theory or an observation of new ways of interaction. In the following we elaborate on how the RtD methodology is applied in this dissertation.

*Investigating the Unit of Analysis*

In a first research phase, we gained more insights in how users organise and re-find digital and physical documents in cross-media PIM information spaces and analysed the opportunities of designing prosthetic memories to overcome re-finding difficulties. The results of this research phase provide answers to RQ 1. The analysis of the user cross-media PIM behaviour enabled us to provide a definition and three main design principles for the proposed cross-media PIM user interfaces. We have used the results from our previous work on cross-media PIM behaviour [99] together with an extensive literature study presented in Chapter 2 to gain first insights into the problem space. We could observe that users make use of contextual, temporal and spatial re-finding cues in both, the digital and physical, information spaces during re-finding activities. In a second user study, we thereby gained insights into how (i.e. dynamics of the interaction strategies) prosthetic memories supporting these re-finding cues are used as well as when and why people use these prosthetic memories. Finally, we investigated technical solutions to enable the design of cross-media PIM user interfaces which led to the proposed formative technical requirements and conceptual system architectures. The results of the unit of analysis, definition and three main design principles of the proposed cross-media PIM user interfaces are presented in Chapter 3, while the technical requirements and the conceptual system architecture are discussed in Chapter 4.

*Design and Implementation of the Proposed Technology*

The second research phase focused on the design and implementation of the technology which enables the design of cross-media PIM user interfaces and therefore provides an answer to RQ2. Based on the aforementioned conceptual system architecture, we implemented three software frameworks. First, we enabled the tracking and storage of temporal and spatial metadata of digital and physical documents and their organisational structures by implementing the DocTr framework [105] elaborated in Chapter 5. Next, we designed and implemented the Context Modelling Toolkit (CMT) [103, 104] presented in Chapter 6. CMT is responsible for determining the document's contextual metadata including which digital and physical documents have been used in which office tasks. Additionally, CMT has been integrated in DocTr in order that DocTr can unify the document's contextual metadata determined by CMT together with the tracked temporal and spatial metadata. Finally, we developed the User Interface Management (CUIM) framework which takes care that interactions can take place across multiple cross-media PIM user interfaces enabling a seamless transition between the digital and physical information spaces. The UIM framework also manages the fact that all available cross-media PIM user interfaces in a user's working environment have to consistently display the required document's metadata during a re-finding activity. We developed the UIM framework on top of the DocTr framework as presented Chapter 7. The presented software frameworks are designed by using the *Design Science Research Methodology (DSRM)* defined by Peffers et al. [86]. The methodology consist of problem identification, defining the objectives for the solution, design and development of the solution, demonstration, evaluation and communication. The implementation of this methodology is given in the particular chapter of each framework.

*Research Results*

In order to technically validate our conceptual system architecture, we have developed various proof-of-concept user interfaces presented in Chapter 7. Our first proof-of-concept user interface is PimVis [100] which allows users to explore their personal cross-media information space through a visualisation. Next, we designed an augmented physical filing cabinet which enables users to explore contextual, temporal and spatial relations between physical folders and digital documents by means of a tangible user interface. Finally, we have developed multiple ubiquitous user interfaces such as File Explorer extensions, an Android application and augmented ring binders. Note that all these proof-of-concept user interfaces have been made interactive with each other in order to provide users with a seamless transition across the digital and physical information spaces. We have further used the various cross-media PIM user interfaces in the two user studies in order to inform the design of cross-media PIM user interfaces. The user studies, presented in Chapter 8, allowed us to define some design implications and gave us further insights in how and why cross-media PIM user interfaces are used. They also provide a validation of the previously defined three main design principles forming the foundations of our envisioned cross-media PIM user interfaces. Therefore, this last research phase answers RQ 3.

### 1.3.2 *Contributions*

The presented dissertation mainly contributes to the domain of Personal Information Management. However, we also made significant contributions to the design of prosthetic memory and to the field of Ubiquitous Computing. We can highlight the following main contributions.

#### *Definition of Cross-Media PIM User Interfaces and the Design Principles*

In this dissertation, we propose the design of cross-media PIM user interfaces as a possible solution to the problem of information fragmentation and inconsistent organisational structures within and across the digital and physical information spaces. This fragmentation and inconsistency often leads to inefficient re-finding activities. While existing solutions only focus on the design of prosthetic memory for re-finding documents in the digital or the physical information space, cross-media PIM user interfaces cross the borders of both information spaces. The presented analysis enabled us to propose a definition for these novel PIM user interfaces including three main design principles. Thereby, cross-media PIM user interfaces must provide a seamless transition between the digital and physical information spaces, provide support for the use of the three re-finding cues including the contextual, temporal and spatial cue and have to be integrated in the currently used PIM applications such as the File Explorer or augment the physical artefacts used for organising physical documents. Finally, the idea of cross-media PIM user interfaces and the design principles have been validated by the implementation of various proof-of-concept applications and two user studies.

#### *General Design Implications for Prosthetic Memory*

While prosthetic memory applications are widely used for various purposes such as reflection and reminding, there is much less known on how, when and why prosthetic memories are used for re-finding information.

The work of Kalnikaité and Whittaker [60] shows that prosthetic memory has to be designed in an easy to access way since users make a trade-off between efficiency and accuracy. Additionally, their results show that the use of a prosthetic memory does not increase over time. However, they did not gain insights into the interaction strategies with prosthetic memory (i.e. do users apply the same re-finding strategy for different tasks) and how these strategies are related to the re-finding mechanism of the organic memory. We gained these insights by a case study including a controlled laboratory user study and qualitative research methods where participants used our Note4U application which provides support for the three re-finding cues. The results indicate that when using prosthetic memory during re-finding activities the interaction strategies are highly dynamic. Moreover, users commonly used multiple re-finding cues within a single re-finding activity as well as across multiple activities where the overall re-finding strategy also changes over time. In addition, the use of the contextual cue significantly increased over time and influenced the choice of prosthetic memory. We can conclude that the design of prosthetic memory for re-finding activities has to take various dynamic aspects into consideration.

*Requirements to Enable Cross-Media PIM User Interfaces*

Existing solutions for tracking digital or physical documents mostly take a system-centric design approach. In contrast to the related body of work, we involved users during the requirement analysis studying subjectively important factors to users with regard to tracking and re-finding functionality of digital and physical documents in the augmented office. The exploratory user study resulted in four user-centric requirements. These requirements include providing re-finding support at the level of organisational structures (e.g. ring binders or folders) in addition to the documents themselves, monitor the flow of a document across organisational structures and users would like to add custom annotations as well as prefer to have supporting PIM tools which are integrated in the third-party applications they are using today. Besides these user-centric requirements, we also defined a set of technical requirements such as the integration with a PIM framework in order to create a unified personal information space and extensibility has to be foreseen at the level of tracking setups, user interfaces and cross-media interactions. Finally, we propose a conceptual system architecture which aligns with the defined requirements and enables the design of cross-media PIM user interfaces.

*Document Tracking (DocTr) Framework*

While existing solutions for tracking digital and physical documents mostly enable tracking functionality within a specific setup (e.g. part of a desk) or application (e.g. File Explorer), we present the Document Tracking (DocTr) framework which enables document tracking functionality across different tracking setups and applications. Moreover, the DocTr framework is responsible to track the temporal and spatial metadata of digital and physical documents as well as their organisational structures. DocTr has been designed in an extensible way such that it can be integrated in any office environment including interfacing with commonly use digital applications such as the File Explorer and applications which augment the physical environment with tracking technology. Additionally, any third-party application can make use of the tracked metadata. The DocTr framework uses our previously developed OC2 PIM framework as a storage backend and our presented Context Modelling Toolkit (CMT) to determine in which task documents have been used.

*Context Modelling Toolkit (CMT)*

In order to provide users with a prosthetic memory which triggers the contextual cue in the organic memory, we have to detect in which context or task documents and their organisational structures have been used. Since tasks mostly differentiate for every individual, we cannot model them in a pre-defined way. Therefore, we investigated existing context-aware frameworks which enable end users to be in control of the context modelling. Although a significant body of related work has been done in the field of end user programming of smart environments, their expressiveness is often too limited to support the complex modelling of daily office tasks. Therefore, we designed the Context Modelling Toolkit (CMT) which enables end users to define complex tasks (i.e. situations) and allows them to use these customised tasks in complex context rules. We enabled this functionality by taking a multi-layered context modelling approach which allows end users, expert users and programmers to collaborate during the context modelling. Note that CMT is designed in a generic manner and can be deployed in any smart environment such as smart homes.

*User Interface Management (UIM) Framework*

In contrast to current solutions that provide support for re-finding digital and physical documents, we aim at a loose coupling between the tracking functionality, data backend and user interfaces. Additionally, the vision of cross-media PIM user interfaces is to have multiple user interfaces in the digital and physical environment which augment the currently used applications and physical artefacts such as a filing cabinet. Moreover, in a common office environment users will be able to interact with their personal information space through multiple ubiquitous user interfaces. In order to enable this distributed user interface aspect of cross-media PIM user interfaces, we have designed the User Interface Management (UIM) framework. The framework implements a Model View Controller design pattern where the model is given by DocTr and the views by the various cross-media PIM user interfaces connecting to UIM. Furthermore, the UIM framework is responsible for the controller of the MVC model. We have evaluated the UIM framework by designing various cross-media PIM user interfaces with the framework.

*Various Cross-Media PIM User Interfaces*

To our knowledge the design of prosthetic memories for re-finding digital and physical documents within and across information spaces is still in its infancy where applications are often designed as proof-of-concept to validate the underlying technology. In contrast, we present various cross-media PIM user interfaces which are designed based on the three design principles including providing a seamless transition between the digital and physical information space, supporting the three re-finding cues used by the organic memory and augment the user's organisational landscape. Our first user interface is PimVis which allows users to explore and search their personal cross-media information space by means of a visualisation that integrates the metadata which triggers the three re-finding cues of the organic memory. The seamless transitions to and from the digital and physical information space is provided by enabling interactions between PimVis and the File Explorer as well as the augmented physical environment (e.g. augmented ring binders). Furthermore, we designed an augmented physical filing cabinet where every folder has been augmented with an LED interface and made interactive by means of touch sensors. Additionally, the filing cabinet includes a tangible and digital control panel where users can browse the filing cabinet's content as well as other documents in their personal cross-media information space. The seamless transition is provided by integrating the augmented filing cabinet with the File Explorer and an Android application. We present a variety of cross-media PIM user interfaces which cross the boundary of the digital and physical information space. To the best of our knowledge there exist no similar approaches to the design of prosthetic memory for re-finding information.

*Design Implications for Cross-Media PIM User Interfaces*

In the last phase of this dissertation, we deployed two user studies to gain insights about the user's behaviour when using cross-media PIM user interfaces. In the first user study, we used PimVis to gain initial insights in the use of cross-media PIM user interfaces, while in our second user study we used the augmented filing cabinet to gain in depth insights in how and why cross-media PIM user interfaces are used. In contrast to related work, our results show that the choice of a prosthetic memory during re-finding activities mainly depends on how well a prosthetic memory fits their current reasoning approach (i.e. used re-finding cues) where the accuracy and efficiency of a prosthetic memory is of secondary importance. Our results further allowed us to define some generic design implications including the observation that users use different re-finding cues across the digital and physical information space, that user interfaces are best integrated in a ubiquitous way in an user's organisational environment and that users aim to be in control of the integration of the user interfaces in their environment where self-development of the interactions between the user interfaces is crucial.

### 1.3.3 *Supporting Publications*

**Research Question 1**
Sandra Trullemans and Beat Signer. 2014. From User Needs to Opportunities in Personal Information Management: A Case Study on Organisational Strategies in Cross-Media Information Spaces. In *Proceedings*

*of the 14th ACM/IEEE-CS Joint Conference on Digital Libraries (JCDL 2014)*. 87–96. DOI: http://dx.doi.org/10.1109/JCDL.2014.6970154

**Research Question 2**

Sandra Trullemans and Beat Signer. 2014. Towards a Conceptual Framework and Metamodel for Context-Aware Personal Cross-Media Information Management Systems. In *Proceedings of the International Conference on Conceptual Modelling (ER 2014)*. 313–320. DOI: http://dx.doi.org/10.1007/978-3-319-12206-9_26

Sandra Trullemans and Beat Signer. 2016. A Multi-layered Context Modelling Approach for End Users, Expert Users and Programmers. In *Proceedings of the First International Workshop on Smart Ecosystems cReation by Visual dEsign (SERVE) co-located with the International Working Conference on Advanced Visual Interfaces (AVI 2016)*. 36–41. http://ceur-ws.org/Vol-1602/paper7.pdf

Sandra Trullemans, Ayrton Vercruysse, and Beat Signer. 2016. DocTr: A Unifying Framework for Tracking Physical Documents and Organisational Structures. In *Proceedings of the 8th ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS 2016)*. 85–96. DOI: http://dx.doi.org/10.1145/2933242.2933254

Sandra Trullemans, Lars Van Holsbeeke and Beat Signer. 2017. The Context Modelling Toolkit: A Unified Multi-Layered Context Modelling Approach. In *Proceedings of the 9th ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS 2017)*. 8. DOI: http://dx.doi.org/10.1145/3095810)

**Research Question 3**

Sandra Trullemans, Audrey Sanctorum, and Beat Signer. 2016. PimVis: Exploring and Re-finding Documents in Cross-Media Information Spaces. In *Proceedings of the International Working Conference on Advanced Visual Interface (AVI 2016)*. 176–183. DOI: http://dx.doi.org/10.1145/2909132.2909261

## 1.4 THESIS OUTLINE

The dissertation is structured into three parts with each part providing answers to one of the three research questions. The first part consists of Chapter 3 where we present three user studies which investigate a user's cross-media PIM behaviour, the opportunities when using prosthetic memory during re-finding activities and user-centric requirements. The results allowed us to define three main design principles for cross-media PIM user interfaces as well as the conceptual system architecture presented in Chapter 4. In the second part, we present our frameworks which are responsible for tracking the required document's metadata in both, the digital and physical information spaces. The spatial and temporal metadata of user interactions with documents are tracked by the DocTr framework and will be presented in Chapter 5. In addition, the DocTr framework also foresees the storage of the tracked metadata and allows third-party applications to easily query this tracked metadata of documents. Next, Chapter 6 elaborates on the Context Modelling Toolkit (CMT) which is, in the context of this dissertation, responsible to determine the contextual metadata of digital as well as physical documents and has been integrated in the DocTr framework. In the last part of the dissertation, we will inform the design of cross-media PIM user interfaces. In Chapter 7 we first present various proof-of-concept cross-media PIM user interfaces and elaborate on how interactions between user interfaces are made possible by the User Interface Management (UIM) framework. Our proof-of-concept user interfaces include PimVis, an augmented physical filing cabinet and some ubiquitous applications. Furthermore, Chapter 8 presents the results of two user studies which allowed us to define multiple design implications and validates the contribution of using cross-media PIM user interfaces during re-finding activities in cross-media fragmented environments. Finally, Chapter 9 provides a summary of our work and a comparison of our findings to related work.

# 2

# BACKGROUND

The presented dissertation covers research related to how people organise and re-find documents in cross-media information spaces as well as the design of cross-media PIM user interfaces. Therefore, we first discuss findings from descriptive PIM research which will give us more insights in the users' organisational and re-finding behaviour. Next, we elaborate on PIM tools which help users organise and re-find digital documents. Finally, we present various techniques which enable the tracking of physical documents and organisational structures and illustrate how they are used in augmented office applications.

## 2.1 HOW PEOPLE ORGANISE DOCUMENTS

Already in the eighties, researchers identified the lack of information organisation by users, since it is a time consuming and cognitively loaded task [24]. Due to this lack of organisation, we often retrieve information in an ineffective way. The understanding and improvement of the organisational and re-finding activities of personal information is addressed by descriptive research on *Personal Information Management* (PIM). A pioneer in the research on how people organise information in their offices is Malone [79]. In his work, filing and piling are formally described as the main organisational strategies. Therefore, Malone is seen as the founder of the most prominent PIM variable, namely the *order* variable which is expressed on an axis ranging from 'order' to 'disorder' (i.e. from filing to piling). Over the past thirty years, this order variable has been investigated by numerous PIM researchers [10].

In Malone's approach, information carriers are seen as individual elements (e.g. paper documents) and organisational strategies can be defined to arrange these elements. Malone's definition of the files and

| | Elements titled | Elements ordered | Groups titled | Groups ordered |
|---|---|---|---|---|
| Files | Yes | Yes | ? | ? |
| Piles | ? | No | No | ? |

Table 2.1.: Malone's definition of files and piles

piles organisational structures in terms of their specific properties is provided in Table 2.1. Files consist of a number of elements which are titled and ordered in a user-specified way such as alphabetically or chronologically. The files (groups) themselves might be explicitly titled and ordered, which is represented by the question marks in Table 2.1. The filing strategy can, for example, be observed in the commonly used filing cabinets. In digital space, the filing strategy is manifested via the folder hierarchy where documents are titled and ordered within a folder. In contrast to the physical space, folders of the folder hierarchy (groups) must be titled and ordered. On the other hand, individual elements (e.g. documents) of a pile do not have to be titled and are definitely not arranged in a particular order. Additionally, piles (groups) are never titled and do not have to be arranged in a particular order. In physical space, piles are often created on the desk or bookshelves while the desktop screen is commonly used in the digital space. Note that for digital piles we followed Malone's definition of piles representing a collection of not optionally titled and non-ordered elements. Therefore, digital piles can, for example, be represented by folders containing documents which are not explicitly labelled by the user (e.g. `New folder`) or they can be constructed by using specific tools such as BumpTop[1].

Both organisational strategies have their advantages and shortcomings. Filing digital and physical documents requires cognitive effort and time [24] due to the classification problem [79, 56]. The classification problem points to the fact that it is often a challenge to label a document with enough information about the document while ensuring that the label fits into the classification structure. Users frequently construct long and complex labels, leading to fuzzy and overlapping categorisations [58].

1 https://code.google.com/p/bumptop/

The construction of complex labels also introduces the problem that re-finding the document becomes less easy over time [24, 71]. Additionally, people have difficulties in deciding the most appropriate classification structure for later retrieval (e.g. alphabetical, contextual or chronological).

Users often do not file away all their personal information but instead construct piles on their desks, bookshelves and on their digital desktop screen. Besides the classification problem as a force to pile information, the lack of time to process all information due to information overload and the uncertainty about the future use and value of the gathered information are other factors that favour the piling of information [119]. Piles show some advantages in these situations but they also provide a much better reminding function than archives as described in the literature [24, 79, 19, 71, 119]. The properties of a pile imply that the documents are not ordered which means that the user needs to browse through the pile. By being confronted with other documents in the pile, a reminder may be triggered. This reminding function is one of the affordances of paper in a general context [92]. A second function of piles is the preservation of the contextual metadata of included documents where the surrounding context of the pile can be used as a cue for later retrieval. This is in contrast to files, where at the time of filing the contextual metadata of a document is not preserved [71]. Several researchers share these findings and point out that the context cue is one of the main advantages of our organic memory for recall [79, 71, 66, 15]. A last function of piles is the spatial property that they provide. The importance of spatial reference is supported by Cole [24] in his research on human aspects in office filing. A hierarchical organisational structure in the physical space, such as applied in a filing cabinet, has much less spatial reference points than piles leading to the fact that the spatial re-finding cue cannot be used to the same degree as during re-finding of documents in piles.

Besides the investigation of filing and piling, various research has been carried out to identify behavioural patterns related to the organisation of digital documents. Behavioural patterns are often defined by combining the order variable (e.g. degree of filing) and a time variable [10]. For example, the work of Whittaker and Sidner [122] observed three organisational patterns in email. *No-filers* are users who rarely file away emails whereas *spring cleaners* sporadically move emails from their inbox to the specific folder hierarchy. Last but not least, *frequent filers* empty their inbox daily by filing most of their emails. Similarly to this work, other research identified different related patterns based on the order variable in email [4, 121], bookmarks [1, 14] and file systems [14]. Likewise, Boardman's study defined cross-tool behavioural patterns for email, bookmarks and the file system [14]. A user's organisational behaviour is expressed by a cross-tool profile and specific profiles were categorised in *pro-organisers* and *neutral-organisers*. These two categories are in fact the "neat" and "messy" behaviours mentioned by Malone [79] but applied in a digital cross-tool setting. In addition to the use of the order variable in defining behavioural patterns in tools as well as cross-tool settings, more recent work uses the same approach to identify behavioural patterns in how people organise micro-notes [113] and to-do's [46]. For example, Van Kleek et al. [113] observed behavioural patterns that are related to the work of Whittakker and Sidner [122], including *minimalists* who are closely related to Whittakker and Sidner's *frequent filers*, *packrats* who are related to *pilers* and *periodic sweepers* that can be compared to Whittaker and Sidner's *spring cleaners*.

## 2.2 RE-FINDING DOCUMENTS

People organise their digital and physical documents since it helps them re-finding the documents when time elapses [56]. In order to support the re-finding of documents in the digital information space, desktop search engines have been given a lot of attention. A group of researchers support the vision that if search engines are improved to better fit the users' information need, all re-finding document issues will be solved [76, 114]. However, other research rebuts this vision. Although current desktop search engines are making major technical advances, people do often not use them [98]. Moreover, search engines are likely used as a last resort when the location of a file is forgotten [12]. A main alternative strategy to search is referred to as *orienteering* [6, 7, 12, 98]. Note that orienteering comes from the game where players need to find a target by navigating through a map such as done during survival trips. In the context of PIM, this strategy is seen in starting the search at a certain point in an organisational structure, such as the folder hierarchy, followed by navigating through the structure in a stepwise manner [98]. Bergman [12] and Teevan [98] both point to the cognitive psychological theory, which states that there is a difference in cognitive effort between recognition and recall, to justify the use of an orienteering strategy. Recall and therefore formulating the file name or other properties of a document is a cognitively more loaded task than the recognition of elements related to a document [108]. The consistency of the folder hierarchy (unless the user re-organises it) contributes to the recognition of a path which leads to the desired document. Furthermore, the spatial awareness as a natural human behaviour enhances the use of orienteering [24]. The followed path during the stepwise navigation gives the user spatial reference points in the information space. The spatial awareness is totally neglected in the use of current search engines as they display the results in a list. Another reason to use an orienteering strategy is the way users add additional functionality to the folder hierarchy. The folder hierarchy is used for purposes such as keeping the surrounding context of documents by creating long and complex labels and as a project decomposition tool. By using navigation throughout the hierarchy, the "hidden" surrounding contextual information related to a project is available to the user. This is in contrast to the use of the search engine where all this relevant surrounding contextual information is lost [58, 98, 59]. However, orienteering might partially fail when the user constructs broad or deep folder hierarchies. The schema becomes more complex and the recognition of related information items are harder to recognise than when the schema would be less complex. Additionally, Bergmann's [12] results on the influence of the depth of the folder hierarchy to the step duration (i.e. time to navigate to a subfolder) shows that users do not spent more time at each step of the navigation process as the hierarchy increases in depth. This results could be explained by the evidence that when the hierarchy depth increases the folder breadth decreases so that the time spent choosing the next folder stays stable. Finally, the orienteering strategy is not only used in folder hierarchies but also in email and bookmark hierarchies [14]. Other research by Henderson [48] inspected the relation between the used organisational strategy (i.e. files and piles) and the use of a re-finding strategy. In both organisational strategies, orienteering is the most significantly used re-finding strategy. Even in piles where one would intuitively think that a search engine would provide some advantages, this is not the case. For example, the content in the email inbox is often ordered chronologically which is enough to re-find an email conversation from where the user can navigate to the needed email.

A last major issue concerning re-finding is the fragmentation of documents across applications, devices and information spaces. In the current digital era, one may have different devices supporting different functionality which are necessary for different tasks, resulting in the fragmentation problem [110]. While the re-finding of documents within folder hierarchies is mostly based on recognition by using the orienteering strategy, this behaviour cannot be applied when a user has to identify the device or tool that contains the needed document. The user needs to fall back to the recall function of the memory to identify the location. Because recalling imposes more cognitive effort, the fragmentation problem can be a burden during re-finding activities. An additional problem is the undesired interruption of switching between schemas of various constructed hierarchies such as the folder, email and bookmark hierarchies [11]. The extra cognitive effort that a user needs to do to switch between these hierarchies is often a burden.

## 2.3 PROSTHETIC MEMORIES FOR DIGITAL DOCUMENTS

Significant research has been carried out to reduce the problems that users experience during organising and re-finding of digital documents. We first discuss PIM applications which explore new ways for organising information. In this category of PIM applications, we can observe two major approaches. First, there are applications which implement the vision where documents should be organised in a similar way as our organic memory. The other approach focusses on new interaction techniques by, for example, providing users with advanced visualisations. Besides applications exploring alternatives to currently used tools, some research has been done which augments the current organisational behaviour of the user in order to help them in re-finding digital documents.

### 2.3.1 *Applications Reducing Information Fragmentation*

To overcome information fragmentation, several PIM applications have been introduced over the last decade. Besides the unification of personal

Figure 2.1.: A timeline in MyLifeBits as shown in [40]

information, these PIM solutions have also focussed on the organisation of information similar to the organic memory.

Some PIM applications provide the functionality to organise and retrieve information based on a timeline similar to the episodic organic memory. In this part of our memory, temporal references are created between the encountered information and its surrounding temporal context such as the date [109]. This approach has been implemented by applications such as LifeStreams [38]. The application automatically stores all created files such as documents, images and email in a chronological list which forms the LifeStream of a user. LifeStream also allows users to create reminders or indicate future events. By formulating a query, the user is able to retrieve information items. The results of a query are returned in the form of a substream of the LifeStream. Similarly to LifeStreams, MyLifeBits has been designed with the idea to let users interact with chronological streams [40]. Figure 2.1 shows the timeline of a user in MyLifeBits. The system supports the creation of collections or substreams of information items, multiple views such as a timeline or a collection of linked resources and the ability to implicitly link information items together based on the timeline. MyLifeBits uses an SQL Server database to store all resources, links and collections.

Nevertheless, the temporal approach lacks the functionality to construct semantic associations between information items.

Besides solutions based on the episodic memory, there are PIM applications which provide the ability to link different digital media similar to our semantic organic memory. The Semantic File System (SFS) links content of the digital file system by providing a layer on top of the file system which keeps the extra link information [42]. The SFS was succeeded by the Rufus system which—in addition to the file system—also included information from email clients [94]. The introduction of the Resource Description Framework (RDF) in 1999 gave some momentum to PIM application design and lead to a number of new PIM prototypes. Moreover, the RDF technology allows to explicitly express links between information items by defining RDF triples in the form of `(subject, predicate, object)` where a subject needs to be a Unique Resource Identifier (URI) which points to a "real world" object whereas an object may be a URI or a literal such as a string. The first PIM application which used RDF as a solution to link information items was HayStack [62]. HayStack links documents based on contextual information such as involved persons or topics. This contextual information is automatically derived from emails as well as from digital documents. The so-called Semantic Desktop solutions [89, 90] are highly related to the HayStack system. In order to import RDF triples in a datastore, they provide modules which crawl third-party application metadata and let the users design their own personal ontology by means of a semantic WIKI. This implies that only contextual information which is available in RDF format can be imported. We may consider this as a major disadvantage since a user's personal information space is not always structured in RDF. More recently, Task Information Management (TIM) has been introduced with the goal to provide task-related personal information in addition to the unification of information [20]. By defining a personal ontology [64] and defining weights (i.e. based on the amount of interaction) on the relationships between the ontology's concepts, a spreading activation algorithm can be applied similar to the organic memory [63]. In this way, the application can present the user relevant information for the task at hand.

The second approach to new ways of organising information is to design novel graphical user interfaces by applying different information visualisation techniques. For example, iMapping [44], shown in Figure 2.2, provides a treemap-like visualisation on top of a semantic

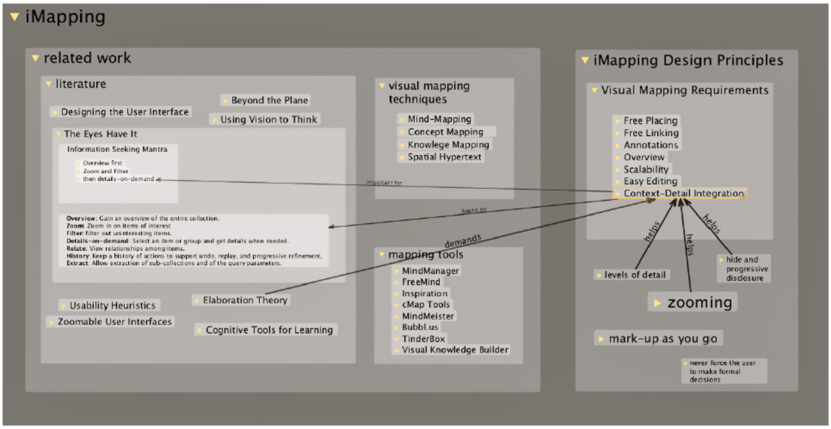



Figure 2.2.: iMapping user interface as shown in [44]

file system. The application uses RDF to encode relationships between documents. The leaves of the tree might contain concepts as well as digital documents. In addition, users can create links between concepts and digital documents across tree leaves. A second visualisation tool is the Personal Information Dashboard (PiD) [2]. PiD is based on the visualisation technique of dashboards. In a dashboard several views are given which display various content of the user's personal information space. For example, a view in the PiD dashboard represents the residence of a user's contacts on a map whereas a second view represents in which application the contact is used (e.g. email, Facebook or Twitter). Such systems allow users to reflect on their personal information which may result in the discovery of new relations between information items. In contrast to visualisations which show semantically related documents, Laevo [55] takes a temporal activity-centric approach to PIM user interface design. The main user interface allows users to define tasks in a timeline view where ongoing tasks are highlighted, tasks can be archived or planned in the future and users can make to-do lists. When opening a task, the user is given the task's desktop environment. In this environment users can access the documents and applications in the state that they stopped working on the task before. Additionally, they have access to the activity context library which is a library similar to the

"Documents" library folder in the File Explorer. In this library, documents related to the particular task are displayed to the user. Finally, there are applications which focus on enabling innovative PIM user interfaces. For example, the ZOIL framework [54] takes an Object-Oriented User Interface (OOUI) design approach where user interfaces are just "views" on top of data objects such as digital documents, information fragments and emails. The so called ZOIL user interfaces are based on six design principles including zoomable user interfaces and other visualisation techniques to interact with the central data repository.

### 2.3.2 *Augmenting the Current Organisational Behaviour*

PIM applications which help users in organising and re-finding of their digital documents are not easily adopted by the end user. Although they foresee significant organising and re-finding functionality, users often prefer to keep on using their current organisational applications such as the File Explorer [7, 14, 23]. Bergman et al. [12] observed various reasons for this preference such as the fact that users significantly value the navigation-based interaction when re-finding in the digital folder hierarchy and the familiarity with organisational structures existing in the physical space. Therefore, research has also been directed to augment the frequently used organisational applications such as the desktop environment or folder hierarchies such as the File Explorer.

The desktop environment can, for example, be augmented with grouping functionality as done in Presto [33]. Users can create groups of digital documents by placing them close to each other. This can be seen as a form of digital piles. During re-finding activities these digital piles can be expanded to explore the included digital documents. Besides the augmentation of the desktop, the File Explorer is commonly augmented with metadata or search functionality. For example, TagFS [13] enables a user to simply tag documents in order to form groups in the File Explorer. A different approach is taken by Laevo [55] and TaskTracer [34] where users are given task-related documents. For example, Laevo uses a standard library folder such as the "Document" folder to show related documents for the current task. In contrast, TaskTracer augments the Start Menu of Windows with the user's recent tasks. When a user selects a task, documents related to the particular task are given in the

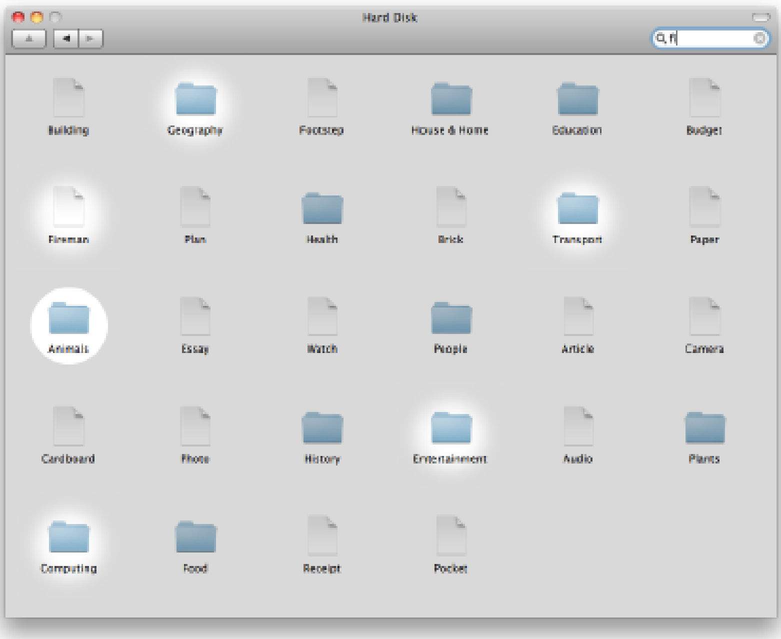



Figure 2.3.: The Search Directed Navigation as shown in [37]

context menu. Another example is to augment the MacOS Finder with recommendation functionality as done by Fitchett et al. [37]. They experimented with different ways to display search results in the folder hierarchy. For example, the Search Directed Navigation application, shown in Figure 2.3, highlights the folders which most likely contain the requested document. The probability is determined by using the AccessRank algorithm which takes into account the navigation behaviour of the user within the search request. Finally, the File Explorer can also be augmented with information concerning the fragmentation of digital documents over different applications, devices and cloud services as implemented by Memsy [39]. By extending the context menu of a digital document, users can explore version and spatial metadata of the particular document.

## 2.4 THE AUGMENTED PHYSICAL OFFICE ENVIRONMENT

Given the fact that physical documents still play an important role in our daily work, various research efforts have been undertaken to integrate physical documents and physical storage artefacts (e.g. a filing cabinet) with digital information systems. Interactive tabletop surfaces are, for example, used in combination with cameras above the desk for augmenting paper documents with digital functionality. Thereby, physical documents are often tagged with a two-dimensional (2D) code as seen in DocuDesk [35] illustrated in Figure 2.4. When a document is recognised on the interactive tabletop surface, DocuDesk shows associated digital content where users can create and change these associations between digital and physical documents.

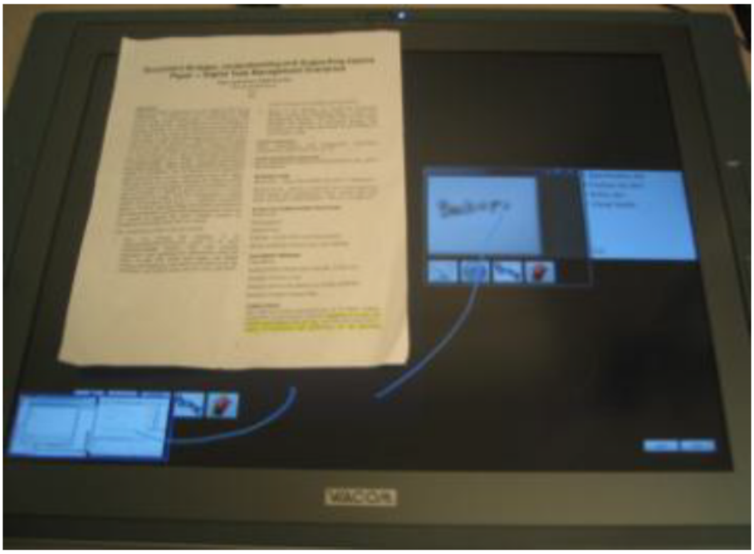
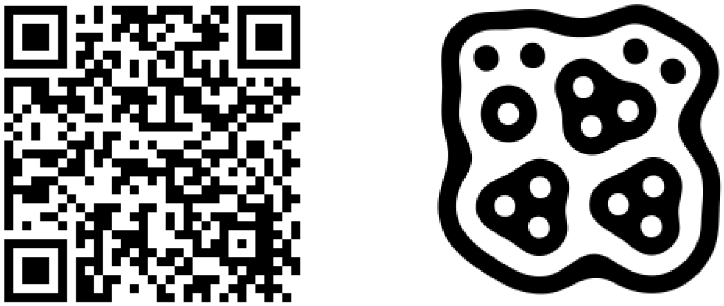


Figure 2.4.: DocuDesk interactive surface as shown in [35]

Over the last decade, we have witnessed an effort in the development of tag-based technologies. For example, the Quick Response (QR) code technology is commonly available on smartphones. QR codes, as shown in Figure 2.5a, are often seen on posters or used in printed advertisements. Users can create and link a QR-code to a url such as a Facebook page



(a) QR code example (b) Fiducial marker

Figure 2.5.: Examples of two-dimensional codes

by simply using one of the available web services such as QR Code Generator[2]. The receiver of the document can scan the code and will be directed to the linked website. While codes such as QR code are only used to identify a paper document, a number of rapid prototyping frameworks have been developed to ease the use of tags for the determination of the position of a tagged object. For instance, the reacTIVision [61] framework identifies and detects the position of fiducial markers, illustrated in Figure 2.5b, within a well-defined surface area. After the recognition of tagged objects in the defined area, the reacTIVision framework notifies registered client applications about the object's relative orientation. Note that the reacTIVision framework is widely used in augmented desk applications. For example, in ObjectTop [65] where users can create piles which can include digital as well as physical documents and iCon [21] which focusses on the use of everyday objects in order to control the tabletop visualisation.

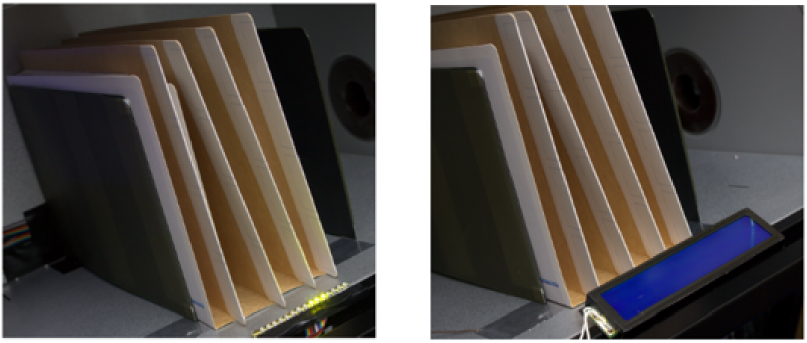
The tagging of physical documents interrupts the user's regular tasks and therefore various computer vision-based document identification solutions have been developed as alternatives to tagging. However, due to changing environmental factors such as the lighting conditions, computer vision-based solutions are often more vulnerable to errors than tag-based solutions. Already in their seminal DigitalDesk system [116], Wellner used feature extraction on captured document images in order to identify which document had been placed on an interactive desk.

2 http://www.qr-code-generator.com

Nowadays, more advanced solutions such as the Scale Invariant Feature Transformation (SIFT) [77] algorithm proposed by Lowe or the Speed Up Robust Features (SURF) [8] algorithm, are used for document recognition. When using the SIFT algorithm, features are extracted from the image (i.e. specific properties of the image such as areas with contrasts are flagged). These features are then compared to the features of available documents which are determined by the system at initialisation. The SIFT algorithm has, for example, been applied in FACT [75] to enable fine-grained cross-media interactions between paper documents and a laptop. In addition to physical documents also other artefacts can be recognised by means of computer vision techniques. For example, the work of Matsushita et al. [80] tracks books in a bookshelf based on the SURF algorithm. Finally, since paper documents often contain a number of unique text blocks, Optical Character Recognition (OCR) techniques can be applied to the text in order to identify a document and any written text can be transformed into a digital form [115].

The aforementioned tracking techniques have been used for tracking physical documents in organisational structures such as piles or filing cabinets. A number of applications augment existing physical organisational structures with tracking functionality in order to provide a digital representation of a specific organisational structure. The work of Lawrie and Rus [73] describes an early application providing a digital representation of a physical filing cabinet. Furthermore, physical documents in piles on a desk can be tracked by using computer vision techniques [67, 88]. More advanced research also focusses on the occlusion of documents on an interactive surface such as addressed in the ObjectTop application where users can create piles consisting of digital and physical documents [65]. Besides these traditional organisational structures, people also use other artefacts such as boxes and drawers for storing physical documents or other physical objects. DrawerFinder [69] provides tracking support for such organisational structures by tagging drawers or boxes and monitoring a user's interaction with a storage shelf containing these tagged boxes.

While the previously mentioned applications monitor one specific sort of organisational structure (e.g. a pile or filing cabinet), during their lifetime documents naturally move between different organisational structures. Therefore, there is a need to track documents across these organisational structures. The Human-Centered Workplace [32] system



(a) LED interface (b) Display interface

Figure 2.6.: The re-finding user interfaces of the SOPHYA framework as shown in [51]

monitors printed documents across organisational structures by augmenting them with a Quick Response (QR) code at printing time. By the use of multiple cameras in the tracked room area the position of the document can be derived. PaperSpace [96] uses a similar tracking approach but adds interactive printed buttons to physical documents. Users can, for example, point to a printed button to request the digital version of a document. While these applications track physical documents across organisational structures, they do not keep track of the internal state of these organisational structures. Moreover, while the Human-Centered Workplace system monitors physical documents in an office environment by using multiple cameras and provides applications the absolute position of tracked documents, it does not model the individual organisational structures (e.g. piles). Although there is a significant lack of applications which model the organisational structures, SOPHYA [51] foresees this modelling step for augmented physical folders. While the physical folders are augmented with an electronic circuit, the bookshelves contain some conductive paths. Users can add documents to the augmented folders and place the folder on one of the conductive paths. SOPHYA keeps track of which folder has been placed where in the augmented office environment and which documents they include. In order to re-find documents, artefacts can be enhanced with re-finding user interfaces such as the integration of an LED strip and display in a bookshelf as shown in Figure 2.6. The LED user interface highlights the LEDs in front of the augmented physical folder containing the searched paper documents while the display shows documents which are stored in the particular folder. Furthermore, the same research team presented Metis [52] which adapted the electronic circuit and conductive path technology used in SOPHYA to support the tracking of other physical artefacts such as books. Metis also enables third-party applications to query the metadata of tracked physical artefacts. SOPHYA as well as Metis focus on the tracking technology and show some limitations in terms of usability since users have to add electronic circuits to every artefact that should be tracked.

## 2.5 DISCUSSION AND CONCLUSION

We can conclude that there is a broad range of descriptive PIM research and related work on the design of prosthetic memories for organising and re-finding digital and physical documents. Most descriptive PIM research focusses on investigating the advantages and issues of the filing and piling organisational strategies in either the digital or physical information space. Additionally, they show which issues users experience during re-finding activities when both organisational strategies are applied. While these observations are of significant value to understand the user's organisational behaviour, they did not take into account the cross-media aspect of document organisation and did not focus on understanding the organic memory's re-finding mechanisms. These insights are crucial to design of cross-media PIM user interfaces which work in synergy with the user's existing organisational behaviour and the organic memory.

We have further seen extensive related work in the design of prosthetic memories for organising and re-finding digital documents. These applications are often designed to work in a similar way as the organic memory by associating digital documents, providing users with a temporal view over their documents or giving users task related documents. Furthermore, since users prefer to keep their current organisational landscape, tools such as the File Explorer are augmented with extra digital functionality. However, existing PIM applications are designed to support one specific approach to organising documents. While in some situations the organic memory might better be triggered by seeing associations between documents, users might need a temporal view to re-find a document on another moment. In addition, we can observe that the presented prosthetic memories providing re-finding support for digital documents do not integrate physical documents although we use them in a simultaneous way. On the other hand, there are solutions for so-called augmented office environments that provide support during the re-finding of paper documents. These applications do not focus on providing extensive organisational and re-finding support to the user and do not integrate well with digital documents. Moreover, research is significantly directed towards the design of tracking technology for paper documents and physical organisational structures while the design of user interfaces which enable the interaction with tracked metadata is mostly left aside. There is clearly a need for cross-media PIM user interfaces that foresee a seamless transition between both information spaces by unifying digital and physical documents.

Part I

# THE FOUNDATIONS FOR THE DESIGN OF CROSS-MEDIA PIM SOLUTIONS

# 3

# CROSS-MEDIA PIM BEHAVIOUR

In a first research phase of the presented dissertation, we investigated the unit of analysis according to the previously mentioned Research through Design methodology. This first analysis includes three steps to go from the observed user behaviour to the definition of the main design principles for the proposed cross-media PIM user interfaces approach. First, we gained insights in the relation between how people organise digital and physical documents and their re-finding strategies. Note that this exploratory user study to investigate organisational and re-finding behaviour formed part of previous work [101]. Therefore, we will only elaborate on those parts of study results which are relevant in the context of this dissertation. Secondly, we deployed a user study to gain insights in the relation between the use of prosthetic memory and the applied re-finding strategies. Next, we involved the user in the design process via a user study which explorers a user's perception of augmented office environments. After the investigation, we unified the results of the three user studies to come to the three main design principles of cross-media PIM user interfaces.

## 3.1 EXPLORING THE ORGANISING AND RE-FINDING STRATEGIES

While there exist a significant amount of previous descriptive PIM research on organising and re-finding behaviour as mentioned in the background section, their research context has been limited to either the digital or physical information space. However, the idea of cross-media PIM user interfaces is that they should cross the border between both, the digital and physical, information spaces. Therefore, we gained insights about the dynamics of organisational and re-finding behaviour across these information spaces. Since this user study has been carried out in previous work, we only include the results for self-containment purposes. The full methodology, data analysis and results can be found in [101] whereas the questionnaire can be found in [99]. Note that parts of this chapter are based on the earlier published paper.

### 3.1.1 *Research Questions*

We defined a number of research questions. Based on the extensive body of related work presented in Chapter 2, the research questions have been selected with regards to the design of the proposed cross-media PIM user interfaces.

**Research Question** (1.1). *Are there additional organisational strategies which are complementary to filing and piling in order to define the degree of order in both information spaces?* While previous research focussed on the use of filing and piling strategies, less is known on semi-structured organisational structures such as letter trays where documents are placed in a labelled container which itself is not organised. This knowledge will give us insights on which categories of organisational structures have to be augmented by cross-media PIM user interfaces.

**Research Question** (1.2). *Is there any coherency and/or dependency between the organisational strategies in the digital and physical space?* When designing cross-media PIM user interfaces with user interface components in both information spaces, we have to know whether there are organisational coherencies and dependencies between digital and physical organisational structures and to which extend these relationships hold. Moreover, we need insights whether the piler/filer profiles hold for cross-media information spaces and whether we do need to design for these profiles?

**Research Question** (1.3). *Do we use the same re-finding cues after applying an organisational strategy in digital and physical space?* It is known that users add significant meta information about a document in the way they organise documents in both individual spaces. However, less is known on the relation between the use of re-finding cues and the organisational structures. These insights will initially allow us to determine which re-finding cues have to be supported by cross-media PIM user interfaces.

### 3.1.2 *Methodology*

We used an embedded multi-case case study research design to gain insights into the mentioned research questions. The first case of the multi-case case study investigated the organisational and re-finding behaviour in the physical space whereas the second case analyses this behaviour in the digital space. Furthermore, the case study took place in two phases. In a first phase, we observed the organisational strategies applied by users in six academic offices. This initial phase gave us more insights about the used artefacts and led to the definition of the *mixing* strategy. In the second phase of the case study, we deployed an online survey to gather user's data. Although surveys are mostly used in quantitative methodologies, they can be applied as a measuring instrument in a case study research design [125]. We had in total 170 respondents with an academic background including professors, postdoctoral researchers, PhD students and (under)graduate students. The online survey measured the following variables:

- **Use of Organisational Structures:** The degree of use of the three categories of organisational structures (i.e. files, piles and mixtures) is measured by asking participants to what degree they use the particular organisational structure by means of examples on a 5-point Likert scale.

- **Ease of Re-finding:** The ease of re-finding within the three categories of organisational structures for each information space is measured by taking examples of the observed structures in the six offices and asking the participant how much difficulty they experience to re-find a document in the particular structure. The difficulty level was expressed on a 5-point Likert scale.

- **Use of Re-finding Cues:** From related work, we can observe that users use three general re-finding cues namely contextual, temporal and spatial cues. In order to measure the use of each of these cues for each category of organisational structures, we created various examples of how people can apply these cues in practise. Users could again express the degree on a 5-point Likert scale.

### 3.1.3 *Results*

The results are structured according to the three research questions (RQ1.1, RQ1.2 and RQ1.3). We only present the main findings which are relevant for the dissertation.

**Research Question** (1.1). *Are there additional organisational strategies which are complementary to filing and piling in order to define the degree of order in both information spaces?*

Similar as to previous work [79, 119, 24, 19, 70] we observed the use of files and piles as main organisational structures. However, during our observations in six academic offices, we also noted the construction of organisational structures which, according to Malone's work [79], could not be classified as files or piles. The observed structures can be classified into three categories as given in Table 3.1. Commonly, these structures have been given a label but the content they contain is not ordered or (not) labelled (e.g. a letter tray) or the content is labelled but the structure is not (e.g. an ordered pile). Besides the construction of such structures in the physical space, we could also observe them in digital space where, for example, some folders are not given a meaningful label (e.g. `stuff` but where the content is ordered and labelled. In order to include this category of structures in the next research questions, we formally defined them as mixtures where the activity of creating mixtures is called mixing.

| **Structure in Malone's terms** | **Example** |
|---|---|
| Labelled structure and unlabelled content | labelled ring binders, folders, letter trays and shelves containing unlabelled and/or unordered documents |
| Unlabelled structure and labelled and ordered content | explicitly ordered documents in the form of stacked documents |
| Labelled structure and inconsistent ordered content | ring binders where the organisation of documents was not consistent over the whole binder |

Table 3.1.: Observed organisational structures with an example

**Research Question** (1.2)**.** *Is there any coherency and/or dependency between these organisational strategies in the digital and physical space?*

The degree that users apply the organisational strategies in both information spaces is illustrated in Figure 3.1. The results of the Wilcoxon signed-rank test show no differences in the degree that files, piles and mixtures are used in the digital and physical information space. Additionally, we could not find positive or negative correlations between the different applied organisational strategies. This shows that we cannot profile users as pilers or filers in a cross-media information space. However, we can observe some relevant qualitative findings from the retrieved survey data. While almost all respondents (110/111) had some degree of physical piles, 30 respondents did not use digital piles at all. Also physical piling has a more moderate use (52 respondents) whereas the degree of use of digital piles is on average equally spread. The same can be observed for the mixing organisational strategy where 30 respondents do not use digital mixing in contrast to 10 respondents who do not use physical mixing.

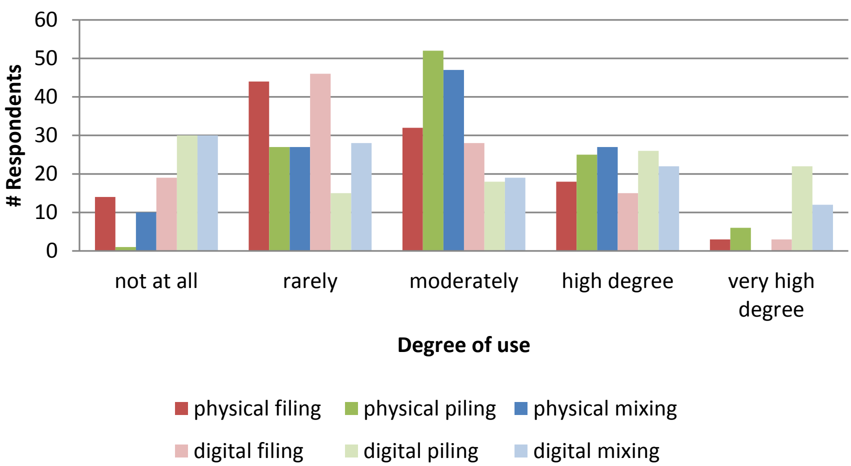



Figure 3.1.: Use of organisational strategies in digital and physical space

Of special interest is the observation of more specific differences in piling. Digital piles are mostly used on the desktop screen whereas physical piles may be on a desk or in shelves. Our results actually reveal that users construct piles on desks and shelves to the same degree without any significant differences. Furthermore, we found a significant positive correlation between the use of piles on a desk and in shelves ($\rho = 0.431, p = 0.000$). This means that the more piles users have on their desk, the more they also have piles in shelves. Besides these findings, we can also indicate that users have at least some piles on the desk or in shelves. Only one respondent had no physical piles at all, whereas 15 respondents had no piles on their desk and 24 respondents had no piles in shelves. This illustrates that the users who had no piles on their desks had at least some piles in a shelve and vice versa. A major difference between desk piles and shelve piles is the kind of information they contain. Our results indicate a much lower access frequency for piles in shelves than desk piles. On average, users access shelve piles on a 'rarely' to 'sometimes' basis (69/90) whereas desk piles are accessed by 70 of 90 valid respondents on a 'sometimes' to 'very often' basis. Note that the access frequency is one of the most important measurements in determining the category of information such as working or archived information [92]. We can therefore state that users store archived information in shelve piles whereas desk piles are used for working information.

When looking at the filing strategy, users apply several techniques to augment digital as well as physical file systems. In order to help them organise digital content, they use tools such as mind maps, wikis and often also the Mendeley[1] application for managing research papers. Nonetheless, these tools are not a perfect solution as stated by one of the respondents: *"I tried out many different ones including, for example, Mendeley for papers, but I was never happy"*. A second observation is the use of tools for decomposition and structuring activities in the digital file system as mentioned by a respondent: *"I use Total Commander by which I am able to compare two directories, use enhanced search functions, rename a list of files etc."*. The previous statement indicates that although earlier research already observed the activity of problem decomposition [58] and structuring [48] in the digital file system, users do use extra tools to help them in these activities. In contrast to digital file system enhancements which happen to be digital by nature, the augmentation of physical filing cabinet appears to be physical as well as digital. Several

1 http://www.mendeley.com

respondents enhanced their physical file systems with digital indexing systems ranging from spreadsheets to digital archiving programs. The two most interesting responses where *"I only use inventories of books in the form of Google document spreadsheets, where I have a column which says location (home/office)"* and *"An Excel sheet to remind me of the files I created and what is inside them and where they are (file number)"*. Besides the digital indexing of physical filing cabinets, users enhance the physical filing cabinet with post-it notes, book cards, stickers on folders as well as notes and they sometimes also use a physical table of contents in ring binders and folders. We can observe that although users do not apply the digital and physical filing strategy in an extensive manner, once they apply filing, they often also augment their file system to preserve the context of the filled documents. In general, we can conclude that there are no coherencies or dependencies between the used organisational structures within and across information spaces. Therefore, we do not have to take into account different behavioural profiles in the design of cross-media PIM user interfaces. We also validated the significant use of the mixing strategy and gained insights in the overall organisational landscape constructed by users.

**Research Question** (1.3)**.** *Do we use the same re-finding cues after applying an organisational strategy in digital and physical space?*

The results of the correlations between the used re-finding cues and the used organisational strategy for both information spaces are shown in Table 3.2. In order to re-find documents in file structures in both information spaces, users mainly use the contextual re-finding cue. This is in line with the observed organising behaviour where users pack extra contextual information into labels and use the structure of the file system in such a way that it reflects the overall context of use as shown in our previous results and in the work of Malone [79] and Kirsh [68]. Additionally, we were able to identify more specific ways on how users keep contextual information in physical filing cabinets. Our survey data shows that users extensively annotate physical documents with reminders as well as make annotations in papers, books and use post-it notes in order to keep contextual information. A second finding is the use of timestamps in re-finding physical documents. For example, participants start their search in a physical filing cabinet by recalling when they had last classified the document. This time-related information provides the starting point for orienteering through the physical filing cabinet. A last cue to support when augmenting a physical file system is the spatial cue. Spatial awareness as a cue in re-finding information has already been introduced by other researchers [24, 57] and our results confirm these findings.

| | | Re-finding Cues | | |
|---|---|---|---|---|
| | | **Contextual** | **Spatial** | **Temporal** |
| Physical space | Filing | ✓ | ✓ | ✓ |
| | Piling | ✓ | ✓ | |
| | Mixing | ✓ | | ✓ |
| Digital space | Filing | ✓ | | |
| | Piling | ✓ | | |
| | Mixing | ✓ | | ✓ |

Table 3.2.: Overview of the used re-finding cues in organisational strategies for cross-media information spaces

Similar as to filing, the re-finding of documents in piles in both information spaces mainly triggers the contextual cue. Commonly, users group contextual related documents together and also annotate the documents with extra contextual information. We did also observe the use of post-it notes in order to preserve the context of physical piles. Additionally, the data of the survey confirms the use of a spatial cue during re-finding of documents in physical piles. Again, the spatial reference points provided by the physical alignment of piles are well-used.

In contrast to digital filing and piling in both information spaces, we see a significant use of the temporal re-finding cue when documents are organised in mixtures. In the physical information space, users provide physical documents with timestamps and use these later on during the re-finding process. Additionally, the stack order is also often used to trigger the temporal re-finding cue. Although we would intuitively think that such a chronological re-finding strategy would also be applied in piles, we could not statistically observe this behaviour for piles. In digital space, users use the timestamp provided by the File Explorer more often than when they re-find documents in a folder that has been organised by applying a filing structure. Finally, the contextual cue is again often used which is in line with the applied re-finding strategies done in files and piles in both information spaces.

## 3.2 THE SYNERGY BETWEEN PROSTHETIC AND ORGANIC MEMORY

The results of our previous work show that users mainly use three re-finding cues during the re-finding of digital and physical documents. Moreover, we could observe that the contextual cue is the most used cue compared to the temporal and spatial cue. Additionally, the use of the cues depends on how well the type of organisational structure and information space provide support to trigger the cue. Although the design of prosthetic memory tools is well-established, there is still limited research on the relationship between the use of prosthetic memory and the use of the re-finding cues during re-finding activities. In the controlled laboratory study of Kalnikaité and Whittaker [60] the use of notes, a dictaphone and ChittyChatty (a tool for temporally co-indexing notes and recorded audio) as prosthetic memory are compared on factors such as usage, accuracy and efficiency. The results show that the technique of temporally co-indexing notes with audio (as applied in ChittyChatty) has been found the most accurate and efficient PM design. Additionally, when using the dictaphone, which is a very accurate but inefficient prosthetic memory, users are willing to take the risk of only relying on their organic memory. Although the research results are based on the accuracy and efficiency of the used prosthetic memory, we can infer a plausible relationship between the use of PM and the re-finding cues. In terms of re-finding cues, we can observe that notes and the ChittyChatty application provide some support for using the contextual cue while the dictaphone does not provide support for any of the three re-finding cues. Therefore, it might be possible that the dictaphone is not used to the same degree as the ChittyChatty application which does provide support for the contextual cue. From this observation we can define the following research questions:

**Research Question** (1.4)**.** *Can we observe the use of the three re-finding cues when prosthetic memory provides support for these cues? Does the use of them change over time?*

**Research Question** (1.5). *Does the accuracy and efficiency of prosthetic memory influence the choice of the used re-finding cue?*

The results of these research questions will enable us to inform design principles for the proposed cross-media PIM user interfaces. Moreover, we will gain insights in how synergy can be achieved between the design of prosthetic memory and the re-finding mechanisms of the organic memory during re-finding activities.

In order to investigate the aforementioned research questions, we have deployed an user study. The study's methodology is similar to the work of Kalnikaité and Whittaker [60] where the use, accuracy and efficiency is compared for various prosthetic memories. Furthermore, we developed the Note4U application as a study platform. Note4U is a Microsoft Word add-in which integrates three prosthetic memories where each prosthetic memory provides support for one or more re-finding cues. In the following sections we will present the Note4U application, the used methodology and the results of our user study.

### 3.2.1 *The Note4U Application*

We designed the Note4U application as a prosthetic memory for re-finding information after a meeting or lecture by enabling the use of notes, recorded audio and the audio transcripts. The graphical Note4U user interface is shown in Figure 3.2 and consists of the following integrated PMs:

- **Notes:** Users can use a standard Microsoft Word document for note-taking.
- **Audio:** The audio player is a simple media player and visualises recorded audio in a waveform.
- **Transcript:** The transcript of an audio fragment is shown on the right-hand side of the notes.

We have chosen to integrate the required prosthetic memories in Microsoft Word since most users are familiar with this application, which might facilitate text editing and layouting during the note-taking phase of our study.

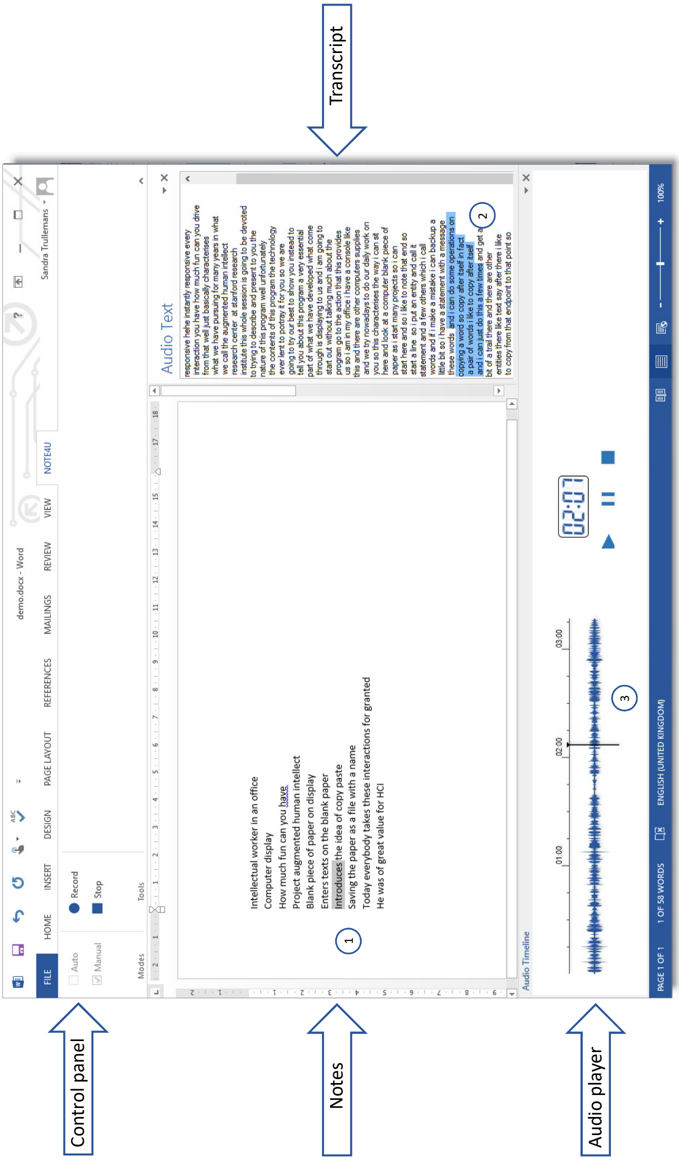



Figure 3.2.: Note4U Microsoft Word add-in. *Control panel*: start/stop the recording. *Notes*: regular Word document to take the notes. *Audio player*: controls for controlling the recorded audio fragment. *Transcript*: panel where the transcript of the audio is shown

*Interactions*

In Note4U, the notes, audio recordings and transcripts are temporally co-indexed, which enables users to navigate between these three prosthetic memories. For example, when a user selects parts of their notes as shown in (1) in Figure 3.2, the corresponding part of the transcript is highlighted (2), reflecting what has been said when the selected part of the notes has been written. In addition, the audio timeline cursor is moved to the start time of the highlighted transcript block (3). Similarly, users can double click in the transcript and the relevant part of the notes will be highlighted and the audio timeline cursor is moved to the corresponding position. Finally, users can move the audio timeline cursor to a specific time and the corresponding part of the notes and transcript block is highlighted. Note that if a user did not take notes at the specified time, only the corresponding part of the transcript will be highlighted. These basic interaction strategies were observed to be used as the main interactions in previous work [123, 83] and can be defined as follow:

- **Navigation:** Users jump to a place in the transcript or audio recording by selecting a part of their notes.
- **Skimming:** Users parse the notes/transcript or move through the audio recording without using another PM as an entry point.

In addition, the transcripts were manually extracted from the audio fragments in order to prevent any bias from potentially inaccurate automatic transcription. Nevertheless, the transcript do not contain punctuations and are just reflecting what people said in the audio fragment. An example of a transcripts is shown in (2) of Figure 3.2. Note that the Note4U application can also automatically extract the transcription of recorded audio fragments.

*Note4U and the Support for the Three Re-finding Cues*

After the note-taking phase, users can use the provided prosthetic memories to re-find necessary information where each prosthetic memory with its supported interaction strategies provides one or more re-finding cues. Moreover, the foreseen navigation interaction strategy between notes and audio or transcript enables users to use the contextual cue since the notes provide a contextual overview of the story. Second, skimming the transcript will mainly trigger the spatial cue where users, for example, can remember that some facts where said at the top or end of the text. Finally, the timeline in the audio panel supports the temporal re-finding cue when skimming the audio prosthetic memory.

*Implementation*

The Note4U Microsoft Word add-in has been implemented in C#. Currently, the Microsoft Speech Recognition Engine[2] with the corresponding dictation grammar is used for the speech-to-text processing in order to also enable the automatic creation of the transcripts. Note that we have foreseen an interface to easily integrate future speech-to-text frameworks. After the recording phase, the audio, transcript and timestamped notes are forwarded to the Note4U engine which performs the temporal co-indexing. Furthermore, the temporal data, audio recording as well as the transcript are stored as part of the XML structure (Office Open XML File Format) of the corresponding Word document. This self-contained approach allows a user to move their document together with the recordings. Finally, the audio timeline and digital clock have been implemented based on the WPF Sound Visualization Library[3].

### 3.2.2 *Methdology*

The used methodology is similar to the methodology that Kalnikaité and Whittaker [60] used in their study investigating when and why people use prosthetic memory. The study took place in a controlled laboratory setting and followed a within-subjects research design. Since we were interested in the use of the re-finding cues which are supported by the interaction strategies (i.e. navigation and skimming) when using audio and transcript PM, we defined three cases. In the first case, participants were allowed to use their notes and audio PM only. In the second case, they could use their notes and the transcript PM only and in the third case they were allowed to use all three prosthetic memories (i.e. notes, audio and transcript). We defined the first two cases in order to measure and observe the interaction strategies and usage of both audio and transcript PM in isolation. Thereby, we could observe the

2 https://msdn.microsoft.com/en-us/library/jj127860.aspx
3 https://wpfsvl.codeplex.com

use of the contextual, temporal and spatial re-finding cue. The third case allowed us to investigate how these PMs are used together and in which situations users use one or the other PM. This gives us more insights into the synergy between the three re-finding cues. For the first two cases, we removed the transcript PM or the audio PM from the Microsoft Word graphical user interface. Finally, we recruited 15 native Dutch-speaking participants with the profile of a knowledge worker. Our participants work in domains where note-taking activities have to be performed on a regular basis, including academic staff, employees in the private sector as well as university students. Furthermore, the age of our participants was between 23 and 58 with an average of 37. Finally, we had a gender distribution of 6 females and 9 males. After the first session, one participant quit the study due to some unexpected agenda conflicts. We therefore removed the data from this participant's first session and the presented results are based on the data of 14 participants. We are aware of the relatively small number of participants but given that we present an exploratory study, the number of participants is sufficient. Each participant received a 10 Euro shopping gift card for an online store given that they participated in all three intervals.

The procedure consisted of two phases. In a first phase, participants were asked to take notes while listening to the three audio fragments. For each audio fragment they used a new Microsoft Word document. Before the note-taking task, they were notified which PM (i.e. audio only, transcript only or both) they could later use in the second phase. The second phase consisted of answering a question set consisting of 6 questions for each audio fragment (given in Appendix B) at the time intervals of the same day as the note-taking phase as well as 7 days and 30 days later. The questions were presented to the participants via a web-based form. During each interval participants could make use of the PM which was allocated to the particular audio fragment at the beginning. For example, if a participant was given fragment one in the case where they could only use audio PM, they received questions about fragment one and they could only use audio PM in the second phase. In order to prevent bias from the audio fragments, questions and used PM, we have used a counterbalanced design with the audio fragments, question sets as well as the order of PM use as factors. Finally, before starting the first phase of the study, participants were introduced to Note4U. Similar as to the study procedure, they first listened to an audio fragment and took notes followed by answering two questions within each PM case. They only started the study when they succeeded in this task and when they did not have any remarks or questions left.

In each case (i.e. audio only, transcript only and the combined case), we measured certain variables. These variables are similar to the ones in the methodology of Kalnikaité and Whittaker [60]. For clarity purposes, we introduce the used variables and explain how they were measured. Besides the quantitatively measured variables, we applied the think-aloud research method to gain insights in the used re-finding cues and re-finding strategy when using the prosthetic memories. Note that the think-aloud research method did not introduce a bias throughout the user study since we could not observe different re-finding behaviour over the time intervals and participants also did not correct their re-finding strategy during the sessions.

- **Usage:** During the observations, we noted down, at each time interval, whether participants used their OM or which PM they used to answer a question. Note that if the notes were used as an entry point to the audio and transcript they were not counted as note usage in the context of a PM. In order to make this distinction, we applied the think-aloud method where users told their strategy during the recall tasks.

- **Accuracy:** Similar as to the methodology of Kalnikaité and Whittaker [60], we graded each answer against a correction scheme. Each answer was given a score between 0 and 5. A grade was allocated to an answer based on the contained keywords and context. For example, an answer which contained all keywords (or synonyms) and the necessary context received a grade of 5. When all keywords were given but no context it received a score of 4 and grades between 1 and 3 were given to answers with parts of the keywords or context. A 0 was given if participants did not fill in an answer or if all keywords and context were wrong. The accuracy of a PM at a certain time interval is the average of these scores. An example of the grading scheme can be found in Appendix B.

- **Efficiency:** The efficiency of a PM was measured by monitoring the time (in seconds) that users spent on answering a question when using a particular PM. Note that we monitored the time when each PM was effectively used.

We have used three audio fragments (i.e. each participant was given another audio fragment for each case). The three fragments are informal interviews where the interviewer calls a person to gain more information about a topic. These topics were about an event in Brussels, giving Dutch classes to prisoners and someone who runs a marathon every day. An example of a part of an audio fragment (English translation) is:

"*And there is a special Brusselicious tram driving across Brussels right? Yes, the tram experience and there is actually a two hours dinner on the tram while driving through Brussels. The dining is also very special. All menus are made by two star chefs, selected from a pool of two Walloon, two Flemish and two Brussels chefs. The menus also change every season and actually it is about dining and exploring Brussels at the same time.*"

Note that we used Dutch audio fragments since our participants were native Dutch-speaking participants. We have selected the audio fragments and constructed the questions in collaboration with two teachers who teach Dutch classes at highschool level. The chosen fragments come from the open access Taalblad[4] teaching platform. We opted for this procedure in order to have audio fragments which were clear to understand and did not contain any dialect or difficult to understand terminology. The fragments had an average duration of 4:45 minutes. For each audio fragment, we constructed three sets of questions where each set contained six questions. An example question is "*What is the tram experience about?*".

### 3.2.3 *Results*

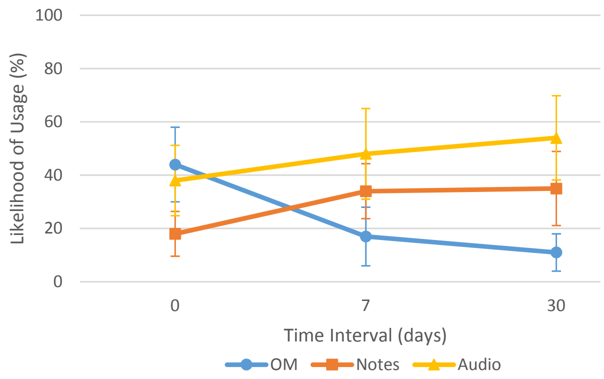
The results are structured based on our two research questions. For each research question, we elaborate on the quantitative and qualitative findings from the logged data and observations. We have used the Friedman test as well as the Wilcoxon Signed Rank test with a Bonferroni correction where appropriate. The statistical results are considered significant if $p < 0.05$.

4 http://www.taalblad.be/zoekresultaat

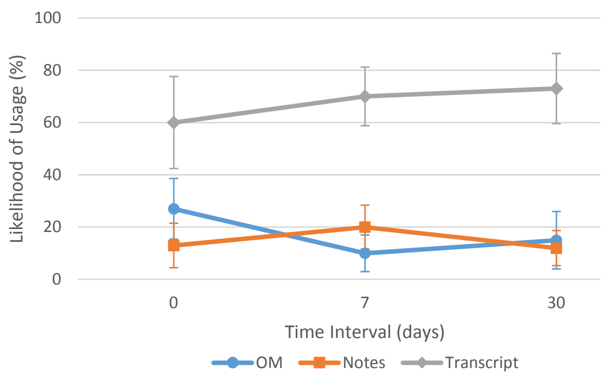
**Research Question** (1.4). *Can we observe the use of the three re-finding cues when prosthetic memory provides support for these cues? Does the use of them changes over time?*

*Overall Usage of Prosthetic Memories*

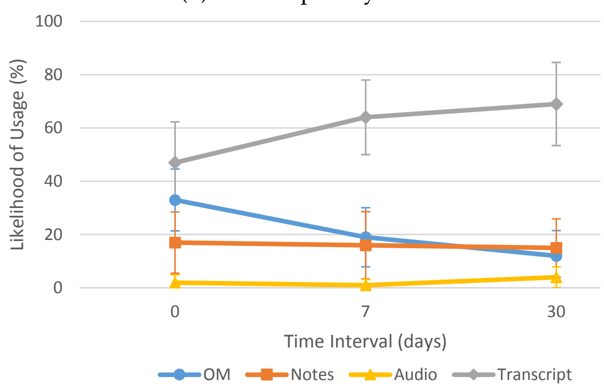
The results of the usage of the provided prosthetic memories are illustrated in Figure 3.3. Both the use of audio and transcripts (i.e. regardless the used interaction strategy) follow a similar pattern when they are used in isolation. Moreover, we could not find a difference in the use of audio ($\chi^2(2) = 3.68, p = .159$) and transcript ($\chi^2(2) = 3.01, p = .216$) over the time interval of 30 days. We also observed that audio is significantly less likely to be used than transcripts after 7 and 30 days as shown in Table 3.3. In the audio and transcript case where users are given the option to use both prosthetic memories, as expected we see that audio is used much less than in the case where transcripts were not available. In addition, in 66% of the cases where audio was used it was due to a previously failed search in the transcript. This behaviour indicates that transcripts seem to have an advantage over audio. Finally, when audio and/or transcripts are provided to the user, the use of notes stays stable over time (Audio only case ($\chi^2(2) = 6.38, p = .061$); Transcript only case ($\chi^2(2) = 3.13, p = .344$); Combined case ($\chi^2(2) = 0.49, p = .976$)). This is in line with previous findings where it has been observed that the use of notes, dictaphone and ChittyChatty did not increase over time [60]. We can conclude that when prosthetic memories provide support for the three re-finding cues, they are significantly used from the first day on and their usage does not change over a period of 30 days.




(a) Audio only case




(b) Transcript only case




(c) Combined audio and transcript case

Figure 3.3.: Likelihood of usage for OM, notes and PM for the three cases over the three time intervals. The error bars define the confidence interval (CI).

| | Same day | 7 days | 30 days |
|---|---|---|---|
| Audio(only)-Transcript(only) | $z = -1.6$<br>$p = 0.113$ | $z = -2.7$<br>$p = 0.007$ | $z = -2.4$<br>$p = 0.017$ |
| Audio(only)-Audio(combined) | $z = -3.2$<br>$p = 0.001$ | $z = -3.3$<br>$p = 0.001$ | $z = -3.3$<br>$p = 0.001$ |

Table 3.3.: The Wilcoxon Signed Rank value ($z$) and significance ($p$) with regard to the observed differences in the use of PM between the audio and transcript only cases as well as between the audio only and combined cases

*The Usage of the Re-finding Cues*

Our results show that navigation is the most used interaction strategy as illustrated in Figure 3.4 and given by Table 3.4. We can also notice that when transcripts are used the interaction strategy changes over time where after 30 days navigation and skimming are used equally. Since navigation is the most used interaction strategy, we can observe that the contextual re-finding cue is mainly triggered. However, users switch to a spatial cue since contextual hints lose their trigger function over time. Moreover, participants mentioned the issue that notes did not provide enough contextual cues any more for using navigation during the last session. In cases where they could not find an appropriate keyword in their notes, they thought that it was more efficient to just skim the transcript rather than trying out various keywords for navigation. When skimming the transcript, participants used spatial references such as "*It was almost at the bottom.*". In contrast, when only audio was available, they used navigation but tried out various keywords situated in the notes until they found the necessary information. As one participant mentioned: "*It will take me too long to play the audio recording forward and backward so I tried to determine the position of the answer by navigating from different parts of the story. But my technique has cost me a lot of effort.*" By investigating different positions in the audio recording, they tried to catch the contextual overview of the story in the audio environment. In addition, most of the participants who applied this approach mentioned the extra cognitive effort that the search imposed. This indicates that they prefer to use the contextual re-finding cue at all costs instead of switching to a temporal cue which would be triggered when applying skimming in the audio. This is in contrast to the observed switch from the use of the contextual to the use of the spatial cue available in the transcript. We can conclude that users mainly prefer to use the contextual re-finding cue. However, in the long term, prosthetic memories should provide enough contextual hints in order that the contextual cue can be triggered. Finally, the spatial and temporal cue are less but still significantly used in long term re-finding activities. Therefore, prosthetic memories should provide support for these re-finding cues as an alternative to the contextual cue.

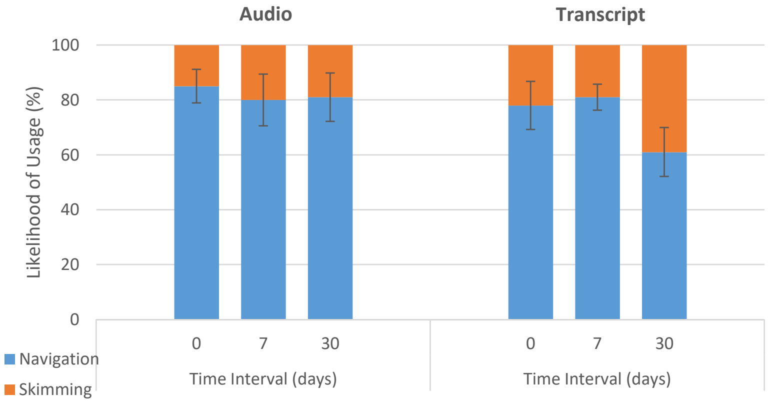



Figure 3.4.: Mean (SEM) of the used interaction over time for the audio only case and for the transcript only case

| | Same day | 7 days | 30 days |
|---|---|---|---|
| Audio skimming-navigation | $z = -3.8$ $p = 0.003$ | $z = -2.6$ $p = 0.009$ | $z = -2.5$ $p = 0.013$ |
| Transcript skimming-navigation | $z = -2.0$ $p = 0.045$ | $z = -2.8$ $p = 0.005$ | $z = -0.9$ $p = 0.325$ |

Table 3.4.: The Wilcoxon Signed Rank value ($z$) and significance ($p$) with regard to the difference in use between the interaction strategies for both audio and transcript.

**Research Question** (1.5)**.** *Does the accuracy and efficiency of prosthetic memory influence the choice of the used re-finding cue?*

The Friedman test shows no significant differences in accuracy for audio and transcript use ($\chi^2(5) = 5.51, p = .358$). The overall mean of the accuracy for audio is $4.17(SE = 0.082)$ and for transcripts it is $4.058(SE = 0.129)$. The accuracy did also not change over time which means that the previously mentioned change in strategy when using transcription (i.e. going over from navigation to skimming after 30 days) does not influence the accuracy and can be called successful. In addition, during our observations we have seen that users often first used navigation to jump to a position in the audio recording. Although we start the audio playback 5 seconds before the co-indexed timestamp, users moved the timeline cursor slightly back on the timeline before starting to listen to the audio. The amount of seconds that they moved the cursor back depended on how much additional information they preferred to re-listen. By applying this strategy, users were given the same contextual information as with the transcript. For example, a participant stated the following during the open interview sessions: *"I always moved the cursor a centimetre to the front since I need to know what was said before. It is then easier to formulate my answer. Anyway, it was just a hack to get the same what you get for free with the transcript."*

Similar as to accuracy, we did not find significant differences in efficiency between audio and transcript for both skimming and navigation as shown in Table 3.5. The overall efficiency of audio and transcript over time is highlighted in Figure 3.5. Although there is no significant difference in efficiency when using audio or transcript PM, users do have the subjective feeling that audio is less efficient than transcripts. During the open interviews they mentioned the subjective inefficiency of audio as a reason for not using it when both PMs are available. We can conclude that the accuracy and efficiency of a prosthetic memory does not play a crucial role in which re-finding cue is used. Additionally, switching between re-finding cues or having more cognitive overload when using a re-finding cue (e.g. as observed when using navigation in audio after 30 days) does not have consequences on the accuracy and efficiency of a prosthetic memory.

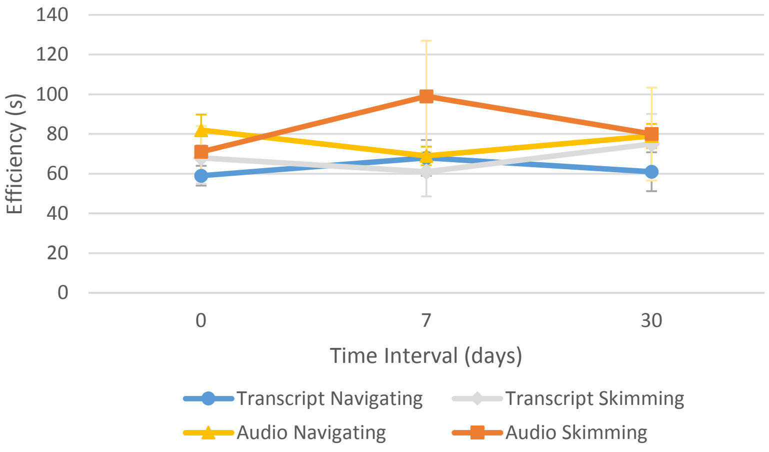



Figure 3.5.: Mean (SEM) of efficiency for navigation and skimming when using audio and transcript over time.

| | Same day | 7 days | 30 days |
|---|---|---|---|
| Skimming Audio-Transcript | $z = -1.3$ $p = 0.180$ | $z = -1.1$ $p = 0.285$ | $z = -0.4$ $p = 0.686$ |
| Navigation Audio-Transcript | $z = -1.8$ $p = 0.071$ | $z = -0.4$ $p = 0.694$ | $z = -1.7$ $p = 0.084$ |

Table 3.5.: The Wilcoxon Signed Rank value ($z$) and significance ($p$) with regard to differences in use between the audio and transcript cases for each interaction strategy

## 3.3 THE USER'S VISION ON PROSTHETIC MEMORY USAGE

In a last phase, we involved the user in the design of cross-media PIM user interfaces. The results of the presented exploratory user study are a number of user-centric design requirements. Furthermore, the presented work forms part of our published paper of the DocTr document tracking solution [105]. Some parts of this chapter have been based on the mentioned publication.

### 3.3.1 *Methodology*

The user study has a user-centric research design. We recruited eleven participants aged between 23 and 56. All participants used a significant amount of physical documents during their working activities. In order to be eligible to participate in this user study, they had to use paper documents on a daily basis. Furthermore, they had different professions such as secretary, social worker, middle manager and managing director.

Since paper document tracking solutions and augmented reality office applications are still in their infancy and often not available commercially, most participants were not aware of these technologies. Therefore, we first introduced our participants to various systems by showing them what they could do with these systems based on screenshots of the corresponding publications such as SOPHYA which is shown in Figure 2.6 and DocuDesk which is shown in Figure 2.4. Note that the introduction of the presented applications focussed on the Human-Computer Interaction aspects and we did not mention the technical details. Additionally, we communicated the possible interactions of existing applications in an objective and neutral manner in order to prevent bias.

In a second step, we conducted semi-structured interviews with the participants. The interview's questions were directed to investigate issues with existing solutions and to explore opportunities for improvement. The main questions among others were: *"For which reasons would you consider to use one of the current solutions?"*, *"Do you see shortcomings or disadvantages of these solutions?"*, *"How do you see the future of tracking technologies?"*, *"What should be the minimal functionality of a tracking solution?"* and *"Can you describe how the ideal tracking solution could be integrated in your working environment?"*. During the interviews we asked additional questions based on the participant's feedback. Note that since the focus was on finding generic requirements, the given questions did not refer to any specific tracking systems.

### 3.3.2 *User-centric Design Requirements*

Based on the interviews and related descriptive PIM research, we derived the following user-centric design requirements.

**Requirement 1** (R1). *Augmentation of the organisational structures*

In descriptive PIM research, organisational structures can be classified in three categories including files (e.g. filing cabinets), piles and mixtures (e.g. unordered documents in a letter tray) [79, 101]. Our interviews showed that users prefer a semantic description of a document's position at the level of the organisational structure such as *"the document is in the ring binder with the label* `Bills`*"*. For seven out of the eleven participants, it would already be enough to just mention the category of the organisational structure containing the requested document, as mentioned by a participant: *"In most cases, this would trigger my spatial cue and then my memory will take it over. I do not think that I will often need the exact location"*. We can conclude that it is not enough to only indicate the exact location of the searched document. Users prefer to also be given information about the encapsulating organisational structure and this in a semantic description. These observations are in line with the natural use of the contextual re-finding cue as observed in our previous work. Cross-media PIM user interfaces should therefore be designed at the level of organisational structures as well as documents.

**Requirement 2** (R2). *The flow of documents and organisational structures*

All participants identified the limited support for tracking physical documents across organisational structures as the main reason for the lack of acceptance of current tracking technologies. They do not see the benefits of installing different tracking setups with their individual applications. In contrast, they would see this as a burden as stated by one participant: *"I think people are becoming crazy with all those different apps everywhere. If all these setups would again require more apps, I first have to find the right app. By then I have found my paper sheet!"*. Besides the flow of physical documents across organisational structures, participants also highlighted that they often move the organisational structures themselves such as when creating a new pile out of two existing piles or reorganising ring binders. In addition to the results of our interview, the flow of documents has also been investigated in descriptive PIM studies. It has been shown that physical documents can contain cold, warm or hot information [92]. So-called cold documents are often archived in a filing structure whereas piles seem to contain mostly hot documents (i.e. documents which are used often) [92, 101]. In addition, it has been shown that a user's personal information space contains a lot of cold documents which are rarely accessed or for which the user simply forgot that they exist [119]. The design of cross-media PIM user interfaces should take the dynamic aspects of documents and the constructed organisational structures into account. Thereby, users can be offered a unified solution and PIM systems can, for example, integrate the history of a physical document's previous positions across organisational structures and make users aware of rarely accessed physical documents.

**Requirement 3** (R3)**.** *Enable the preservation of custom metadata*

As mentioned before, most participants prefer a semantic description of a physical document's position. In addition, the interviews revealed that users frequently would like to provide their own metadata about specific physical documents. Note that this custom metadata does not necessarily consist of positional data but can contain arbitrary annotations. Users prefer to add custom metadata as observed in current practice where they annotate documents with contextual information [92]. One cause can be seen in the fact that when applying the filing strategy, the overall context of a document is lost [59]. A flexible document tracking solution should therefore offer a mechanism for managing various kinds of positional as well as custom document metadata. This metadata can then be provided to the user via the cross-media PIM user interfaces.

**Requirement 4** (R4)**.** *Integration with third-party applications.*

Eight of the eleven participants preferred to have the document tracking metadata available in their frequently used tools. A number of participants mentioned that they would find it convenient to have a digital representation of physical documents and their metadata in applications such as Evernote where these physical documents could then be included in digital notes. Other participants proposed to just make the data available in the File Explorer in order that they could organise physical documents together with their digital media. These findings are in line with previous work. It has been observed that users hold on to their familiar tools when it comes to PIM [12]. In addition, SOPHYA which is closely related to the presented work, aims for a decoupling of tracking technologies and third-party applications [51]. Therefore, it should be possible to integrate a tracking solution with third-party applications and these applications should have easy access to any document tracking metadata.

## 3.4 CROSS-MEDIA PIM USER INTERFACES DESIGN PRINCIPLES

The results of our first user study presented in Section 3.1 show that users apply the three categories of organisational strategies (i.e. filing, piling and mixing) in both information spaces. We could also observe that during re-finding activities users prefer to use one or more re-finding cues (i.e. contextual, temporal and spatial). However, since the organisational structures do not provide enough support to trigger the re-finding cues, users do major efforts to keep the metadata of organised documents. Moreover, we have seen that they augment digital and physical documents with annotations, use applications to keep an inventory of their personal information space and augment physical storage artefacts with a digital or physical index which contains the necessary contextual, temporal or spatial metadata. Furthermore, our results also show that even if they do these efforts, re-finding documents is still not easy. Therefore, we can conclude that there is a clear need of prosthetic memories which help users during their daily re-finding activities in and across the digital as well as physical information spaces. Note that the design of these prosthetic memories has to be customised for each individual since users have significantly different organisational landscapes in both information spaces as shown in our first user study. In order to overcome the burden during re-finding activities of documents situated in organisational structures, we propose the design of cross-media PIM user interfaces. These user interfaces can be small applications in the form of simple File Explorer extensions or can be complete augmentations of physical storage artefacts such as a filing cabinet or desk. Since cross-media PIM user interfaces can take various forms depending on the user's organisational landscape or preferences, we defined three design principles. These design principles should be followed in every form of design of cross-media PIM user interfaces. We defined the three design principles based on the results of the aforementioned three exploratory user studies.

**Design Principle 1** (DP1). *Enabling a seamless transition between the digital and physical information space*

We have observed in the first user study that users still use a significant amount of physical documents and organise them in the three categories of organisational structures. Remarkable was that almost all users had piles of paper documents on their desk or bookshelves. Additionally, we could not see a significant negative or positive correlation or dependency between the use of organisational structures across the digital and physical information space. Basically, if users would mainly use digital documents, we should have observed a negative correlation with the use of physical documents. This shows, beyond doubt, that digital and physical documents are mainly used in a simultaneous manner. Additionally, our third user study which investigated user-centric requirements illustrates that users ultimately prefer a cross-media PIM solution where physical documents have been integrated in their currently used tools such as Evernote and the File Explorer. Finally, we could also already observe cross-media PIM behaviour in the strategies which users apply to augment their physical information space. For example, filing cabinets are augmented with a digital index as mentioned in the results of the first user study. Since PIM behaviour crosses the boundary of the digital and physical information space, we have to enable a seamless transition between both information spaces. Digital documents should be made available in the physical organisation landscape and a digital representation of paper documents should be provided in the digital information space. Additionally, they should be made interactive with an interaction which enables users to easily "jump" between information spaces, for example, by indicating the position of the physical document in the physical environment when the digital representation is selected.

**Design Principle 2** (DP2). *Providing support for the use of the three re-finding cues including the contextual, temporal and spatial cue*

While users naturally use three re-finding cues during re-finding activities, the way they organise digital and physical documents is not compatible with these re-finding strategies, as shown by the results of the first user study. Therefore, in the second user study, we have investigated the use of the re-finding cues when prosthetic memory provides triggers for the cues. Our results show that it is beneficial to integrate support for the re-finding cues in prosthetic memories. Users extensively used the available prosthetic memories in the Note4U application, regardless of the time elapsed between the moment of processing the presented information and the re-finding activity. We could see that the navigation interaction strategy was mainly used. This implies that users prefer to use the contextual re-finding cue as compared to the temporal and spatial re-finding cue. However, the use of re-finding cues in an augmented environment is dynamic. In the long term, prosthetic memories may not provide sufficient contextual data to fully trigger the contextual re-finding cue. For example, we saw that often notes did no longer trigger the contextual re-finding cue after a period of 30 days. In order to compensate this loss of contextual information, users switched to the spatial re-finding cue. Note that a cost/benefit analysis is made when choosing to switch to another re-finding cue. If the cost is too high to switch between prosthetic memories, such as observed in skimming audio fragments based on temporal hints, users will still depend on the contextual re-finding cue although this interaction requires more cognitive effort. The results show that the outcome of the cost/benefit analysis and potential switching between re-finding cues does not affect the accuracy and efficiency of the eventually used prosthetic memory. Therefore, synergy with the organic memory can be achieved by providing support for the three re-finding cues in the design of prosthetic memories. This support will enable the organic memory to self-estimate the most accurate and efficient re-finding strategy. Additionally, the dynamic aspect of the use of the re-finding cues has to be taken into account. In contrast to providing one ideal solution as mainly done in related work for re-finding digital documents, we should provide users the free choice on how and when they want to be helped. In this way, thorough synergy can be achieved with the organic memory.

**Design Principle 3** (DP3)**.** *Augmenting the currently used organisational structures in both the digital and physical information space*

The third design principle is based on findings from the first and third user study. The first user study indicates that users construct organisational landscapes which vary across individuals as well as the digital and physical information space. Therefore, one solution will not meet the user's organisational and re-finding challenges. By augmenting the currently constructed organisational structures of the user, we will be able to provide highly customised augmented working environments. Due to the fact that there are no dependencies between the use of organisational structures within and across information spaces, the augmentations can be done for each individual organisational structure without the need to take into account any consequences for the user's organisational behaviour. However, the augmentations should pay attention to the dynamic aspects of organising documents. In the third user study, we have seen that users value the fact that augmentations for their PIM activities should integrate the flow of documents and organisational structures. Additionally, prosthetic memories should be integrated in their currently used applications since they are not willing to switch to another application during their re-finding activities.

## 3.5 conclusion

In this chapter, we presented three exploratory user studies which enabled us to gain insights in the unit of analysis and to propose the concept of cross-media PIM user interfaces as a way to decrease the issues during re-finding activities in cross-media information spaces. While the first exploratory user study focussed on how users organise and re-find their documents within and across the digital and physical information space, the second user study focussed on exploring how the re-finding cues are used when prosthetic memory provides support for them. Lastly, we involved users in the design process of cross-media PIM user interfaces. The results show which aspects of augmented office environments are mostly valued by the users. By combining the outcomes of the three user studies, we have shown why there is a need for the proposed cross-media PIM user interfaces and how the three main design principles have been defined.

# 4

# FROM THE USER TO TECHNOLOGY

In the previous chapter, we have investigated the unit of analysis which resulted in the aim for cross-media PIM user interfaces where the design of these novel user interfaces should be based on the three design principles. They should provide a seamless transition between the digital and physical information space, provide support for the use of the three re-finding cues triggered in the organic memory and augment the user's organisational landscape. In this chapter, technical requirements are defined followed by the proposed conceptual system architecture. The system architecture has been decomposed into three main research units (RU) which are introduced in the following sections. The next three chapters then elaborate on the implementation of the components described in the research units. The resulted software framework from the three research units provides an answer to RQ 2 of this dissertation on how to enable the design of cross-media PIM user interfaces. Note that the outcome of each research units resulted in stand-alone software frameworks which can be used individually by third-party applications depending on the required functionality.

## 4.1 TECHNICAL REQUIREMENTS

We identified a number of technical requirements for offering the functionality described in the design principles of cross-media PIM user interfaces. The following requirements are a continuation of the previous mentioned user-centric requirements.

**Requirement 5** (R5). *Extensibility at the level of tracking setups and user interfaces*

Since users have highly customised physical office environments and use various applications to organise their digital documents, we cannot determine in advance for every individual which tracking and re-finding functionality we should foresee for their specific working place. Therefore, a tracking and re-finding solution should be extensible via a plug-and-play architecture. At the level of document tracking this means that every tracking setup which monitors a specific part of the digital or physical environment can be handled as a single component. Consequently, users or developers can combine different tracking setups depending on the user's environment. Similar to extensibility at the tracking level, we should enable the plug-and-play principle at the level of cross-media PIM user interfaces. Thereby, users can decide themselves which physical artefacts or applications have to be augmented with re-finding support. By providing such an extensibility at both the tracking and user interface level, we will enable DP3 and R1 concerning the aim to augment the currently used organisational structures as well as R2 to make it possible to monitor the flow of documents across organisational structures. Furthermore, the seamless transition between the digital and physical information space, as required by DP1, can be provided due to the fact that digital as well as physical documents are tracked by a single generic framework and user interfaces can be made available across both information spaces.

**Requirement 6** (R6). *Managing unique identifiers of documents and organisational structures*

Due to the possibility of combining tracking setups with their own unique document identifiers, a general document tracking solution has to provide a mechanism for managing and mapping the different unique identifiers that might be assigned to a single digital or physical document by the different tracking solutions. The challenge lies in the fact that unique identifiers can take different formats. For example, a document recognised by the SIFT [77] algorithm will be identified by a set of extracted features while tag-based recognition frameworks use an integer or string as identifier. By supporting multiple unique identifiers for a single paper document or organisational structure, the flow of items across different organisation structures and tracking setups can be managed R2.

**Requirement 7** (R7). *Tracking and storing of contextual, temporal and spatial metadata of digital and physical documents as well as their organisational structures*

While most current tracking solutions for digital and physical documents only track the position of the document or organisational structure [80, 65, 32], we need to also monitor contextual and temporal metadata in order to enable DP2, the support for the three re-finding cues. Additionally, the tracked document's metadata should be stored independently from the used tracking setup which derives the document's metadata. The separation of concerns between the tracking functionality and the storage of metadata will allow third-party applications to use the document's contextual, temporal and spatial metadata, as required by R4, without the need to know how the metadata has been derived.

**Requirement 8** (R8). *Integration with a central PIM repository*

Within PIM research, frameworks such as Gnowsis [90] and HayStack [62] have been developed for digital document management. Their main advantage is that they provide the user with a central repository of their personal information. Thereby, information fragmentation is reduced and re-finding digital documents becomes more efficient. The long-term study by Sauermann and Heim [91] highlighted the promising future of such central repository PIM frameworks. However, most of these PIM frameworks only support digital media. In our previous work [102], we developed the Object-Concept-Context (OC2) PIM framework which is a central repository for personal information management that also integrates physical documents. By using the OC2 framework or a similar cross-media PIM framework, we can offer a unified cross-media PIM solution. Moreover, we can use these frameworks to store the tracked contextual, temporal and spatial metadata and therefore contribute to enable support for the three re-finding cues across the digital and physical information spaces as aimed in DP2. Additionally, the use of a central repository unifies digital and physical documents which is necessary to enable a seamless transition between information spaces as required in DP1. Finally, PIM frameworks commonly offer the functionality to store custom metadata of documents which is aimed by R3.

The aforementioned technical requirements ease the formulation of the proposed system architecture. While the following sections describe how the technical requirements have been achieved at a conceptual level in the proposed system architecture, the next chapters elaborate on how they have been achieved in the implementation of the overall presented PIM solution.

## 4.2 OBJECT-CONCEPT-CONTEXT (OC2) FRAMEWORK

In previous work, we have developed the *Object-Concept-Context* (OC2) PIM framework [102]. Since the OC2 PIM framework unifies digital and physical documents, we have used the framework in the context of the presented dissertation in order to fulfil R8. We will first discuss the OC2 framework at a conceptual level in order to clarify the introduced terminology. Next, the OC2 metadata model is presented which has been extended in the presented DocTr document tracking framework discussed in Chapter 5.

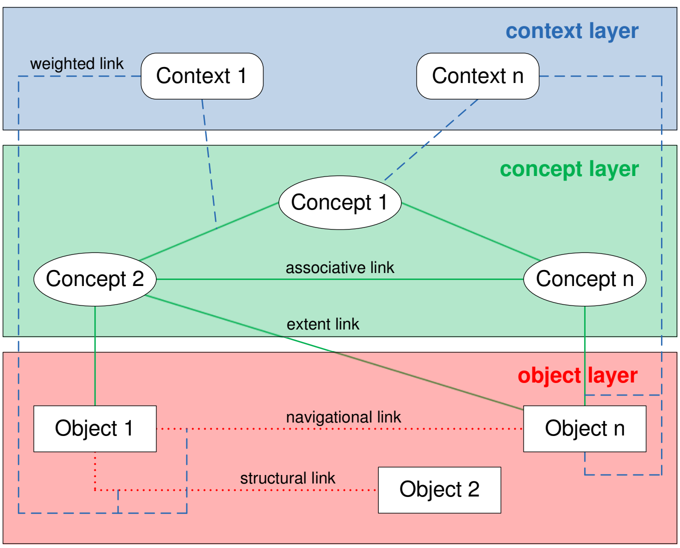
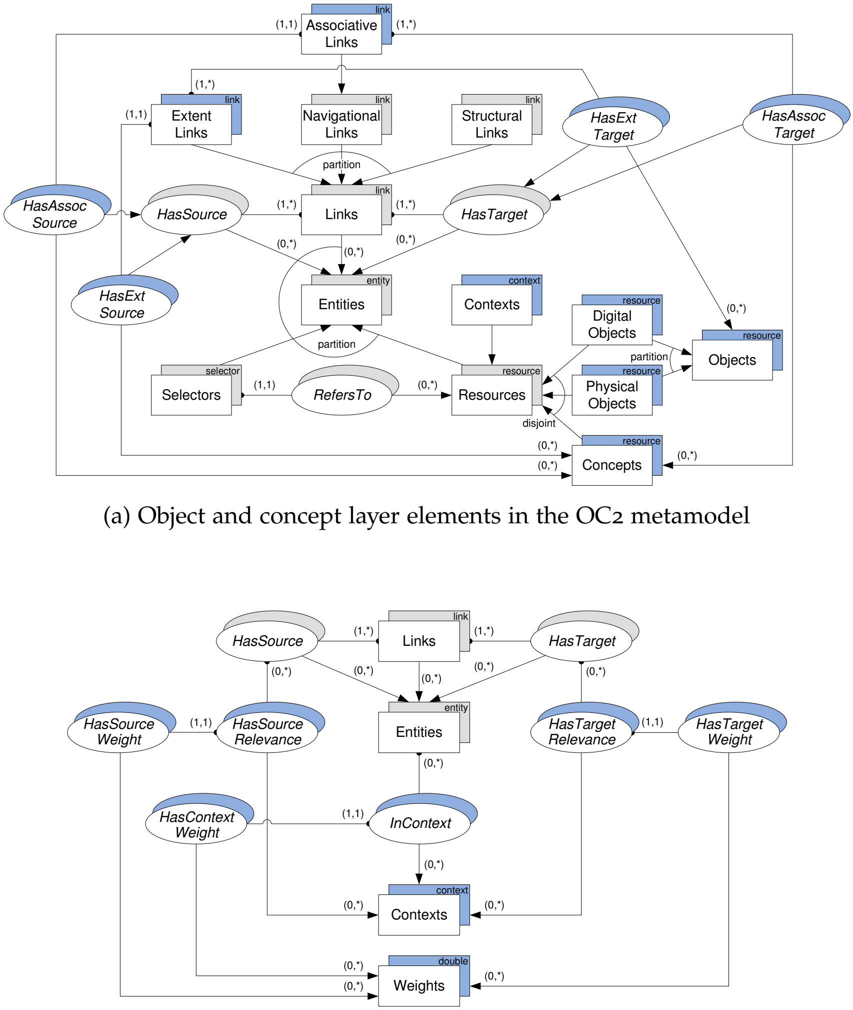



Figure 4.1.: Conceptual model of the OC2 PIM data model

The OC2 conceptual framework for cross-media PIM systems consists of the three *object*, *concept* and *context* layers outlined in Figure 4.1. The object layer contains objects representing real-world elements which can be observed in physical or digital space. An object might, for example, stand for a digital or physical document. Objects can have relationships with each other. These relationships are defined via *navigational* or *structural links* as illustrated by the dotted red lines in Figure 4.1. Navigational links are used to express navigational paths between digital and physical documents while structural links provide a way to express structures within documents. The second layer is the concept layer. The concept layer consists of conceptual elements (e.g. words or sentences) representing abstractions of observed objects. In the context of PIM, concepts can, for example, be the label of a folder. Similar to the object layer, concepts can have relationships with each other. These relations are expressed by *associative links*. However, concepts can also have a relation with objects from the object layer. These kind of categorical relationships are defined by *extent links*. In practise, an extent link defines, for example, which documents belong to a specific folder. The solid green lines in Figure 4.1 illustrate the associative and extent links. Finally, at the top we can see the context layer. The context layer consist of contextual elements which can represent any contextual information such as a task. In order to achieve synergy with the human organic memory, we have enabled the application of a spreading activation algorithm since human memory retrieves information by spreading activation [3]. Moreover, objects, concepts and the previously introduced different links can have relation to a specific context. Additionally, this relationship can be given a certain importance in the form of weight allocation. The contextual relations are illustrated by the blue dashed lines in Figure 4.1.

The aforementioned OC2 conceptual model has been implemented as a domain-specific application of the Resource-Selector-Link (RSL) hypermedia metamodel [95] as shown in Figure 4.2a. While the entities defined in the RSL metamodel are illustrated in grey, the blue coloured entities show the extensions made for the OC2 metamodel. The RSL metamodel enables bidirectional many-to-many linking functionality between entities. Moreover, links can be instantiated between `Resources` (i.e. represent any media), `Selectors` (i.e. specific part of a resource) and `Links` themselves since these three collections have been defined as a subcollection of the `Entities` collection. Furthermore, depending




(a) Object and concept layer elements in the OC2 metamodel



(b) Integration of context elements

Figure 4.2.: OC2 framework as domain-specific RSL application

on the type of link, a link can belong to the `Navigational Links` or `Structural Links` collection. Note that in the RSL metamodel links have been modelled as first class entities where the `HasSource` and `HasTarget` associations hold the actual pointer to the source and target entity of the link. In practise this means that when a link is created between, for example, two resources, we will instantiate a `Link` object and add this object together with the resource objects to the `HasSource` and `HasTarget` association.

The RSL metamodel has been extended at three positions. First, we defined the collections `Physical Objects` and `Digital Objects` as subcollections of the `Resources` collection since it is informative to know to which information space a document belongs. Similarly, the collections `Concepts` and `Contexts` have been defined since they are the elements of the concept and context layer as specified in the OC2 conceptual model. The introduced links between objects in the object layer are already modelled by the `Navigational Links` and `Structural Links` collection of the RSL metamodel. Likewise, we have defined the `Extent Links` collection as a subcollection of `Links`. However, the introduced associative links between concepts have been modelled as a subcollection of `Navigational Links` since they represent navigations between concept entities. Note that associative and extend links can only have one concept entity as a source as indicated by the cardinality constrained on the `HasAssocSource` and `HasExtSource` associations. We modelled these links as one-to-many relationships due to the fact that concepts are uniquely identified by their description in terms of other concepts or objects as done in the organic memory [16]. Finally, we have added an `InContext` association between the collections `Entities` and `Contexts` in order to express that elements of the object and concept layer as well as their links can have a relation to a specific context as shown in Figure 4.2b. The relevance of this relation is modelled by introducing the appropriate associations between the source and target associations of links and a weight collection.

## 4.3 TRACKING DOCUMENTS AND THEIR STRUCTURES

As part of this first research step, we extended the existing OC2 framework at the two levels highlighted by the red parts of Figure 4.3 in order

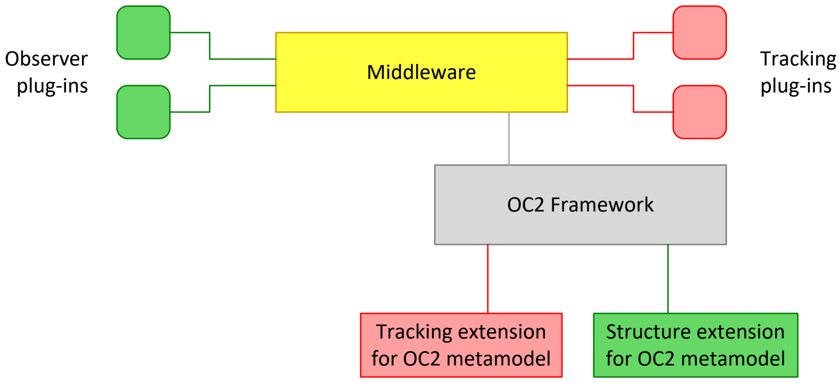



Figure 4.3.: Extensions of the architecture to enable the tracking of documents and their structures

to achieve extensibility for tracking setups (R5) and managing different unique identifiers (R6). First, we extended the core OC2 metamodel with knowledge about which documents are tracked by which tracking setup and the fact that documents can have multiple unique identifies depending on the associated tracking setup. Secondly, to overcome hard-coded tracking functionality, there needs to be a plug-and-play mechanism which allows end users and developers to use various tracking setups according to the arrangement of the user's digital and physical environment. Therefore, we implemented a middleware layer on top of the OC2 framework which is shown in yellow in Figure 4.3. Tracking plug-ins have to inform the middleware when digital and physical documents are moved. The middleware will query and update the OC2 framework with the new state of the cross-media information space. However, it is not enough to only track the position of documents but we also need to track their organisational structures (R1) and monitor the flow of documents between organisational structures (R2). In order to enable the tracking at the level of organisational structures, we have further extended the OC2 framework with the knowledge of the three categories of organisational structures (i.e. files, piles and mixtures) and which documents they store. Similar to the tracking of individual documents, we provide a plug-and-play mechanism via observer plug-ins to monitor interactions with organisational structures as shown in green in Figure 4.3.

Finally, the middleware and the OC2 metamodel have been extended to derive and store the necessary temporal document's metadata and organisational structures. Moreover, when interactions such as moving documents between organisational structures or working on a document are detected, we have to store when the interaction took place and what kind of interaction it was.

## 4.4 CONTEXT-AWARENESS OF DOCUMENT INTERACTIONS

While the first research step focusses on tracking of the positions of documents and their organisational structures as well as the temporal metadata related to the interactions with documents, we need to track and store contextual metadata as well (R7). However, tracking contextual document information and their organisational structures is far from trivial. Moreover, users have personalised ways of organising documents and the context in which they use documents such as tasks varies across their profession and daily activities. Therefore, one solution will not fit all users' behaviour. We have previously discussed existing activity or task-centric PIM applications in Section 2.3.1. One approach is to let the user manually define their tasks as, for example, required in Laevo [55]. Since this approach requires effort and time from the user and interrupts their daily activities, it is often not desired. More advanced applications try to automatically categorise documents in tasks which can be automatically defined by using techniques from Artificial Intelligence such as implemented in TaskTracer [34]. Nevertheless, research from the field of ubiquitous computing shows that automatic derivation of complex user-centric contexts, such as a knowledge task, can be error prone since users may have different behaviours and routines [9, 81]. Therefore, current research in ubiquitous computing is directed to give users, partial, control over their smart environments in order to fit the environment to the user needs [47]. Over the last few years, we have therefore seen an emerging trend towards visual programming tools for context-aware applications based on simple *"IF this THEN that"* rules where the *"this"* part is often formulated in terms of sensor input or simple application states such as notifications. However, simple *"IF this THEN that"* rules are not well-suited to model complex user-centric tasks which are required when modelling daily working activities [111]. Since

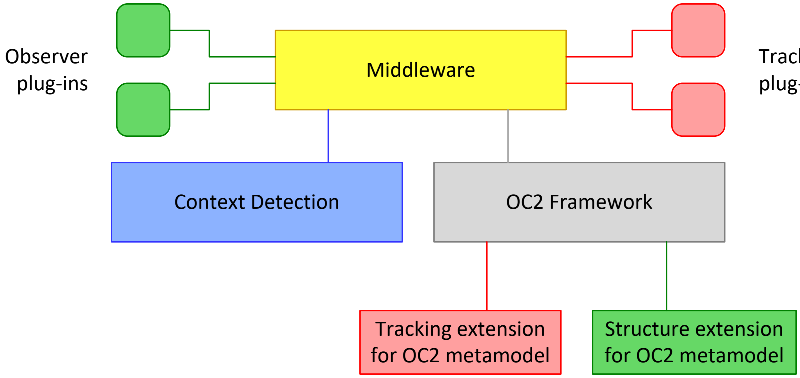



Figure 4.4.: Extensions of the architecture to enable the tracking of contextual information

context detection is a challenging task, we first investigated existing solutions which could enable the tracking of contextual information of documents and organisational structures. However, current solutions did not foresee the necessary expressiveness required for tracking daily tasks. Therefore, we developed our own context modelling framework. Note that the framework is a stand-alone solution which means that it can also be used in other settings such as smart homes. In a second phase, we unified the context modelling framework with the existing middleware as shown in blue in Figure 4.4. Moreover, the context modelling framework notifies the middleware when the user switches tasks. When document or organisational structure interactions are detected, the document or organisational structure is assigned to the current context of the user by the middleware in the OC2 framework.

## 4.5 CROSS-MEDIA PIM USER INTERFACE MANAGEMENT

In a last phase, we extended the middleware with a User Interface Management (UIM) component as shown in purple in Figure 4.5. The component realises a pluggable user interface mechanism. This enables us to provide the necessary extensibility at the user interface level (R5). The UIM component is responsible to register available user interfaces

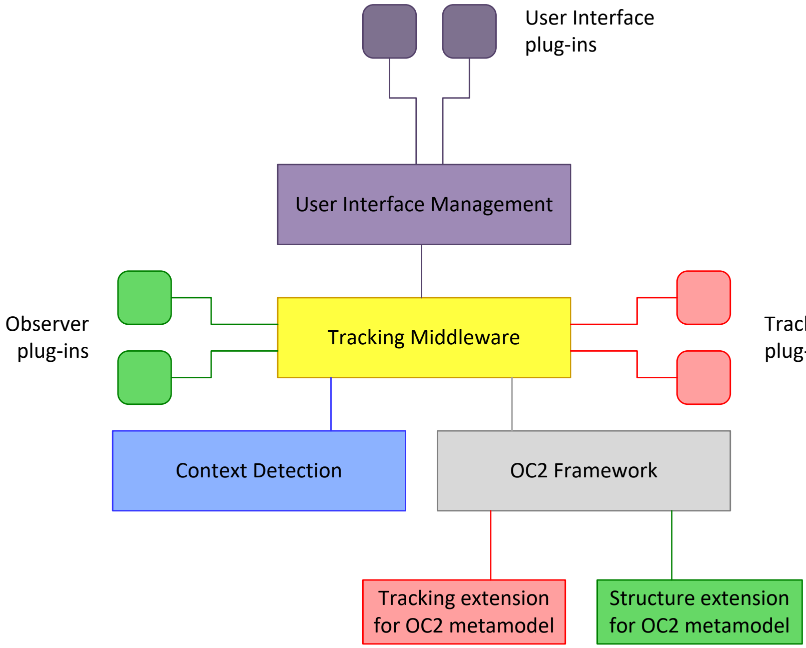



Figure 4.5.: Extensions of the architecture to enable the management of the user interfaces

and to forward updates in the model (i.e. the extended OC2 framework) to the registered user interfaces. Additionally, interactions between user interfaces are made possible to enable a seamless transition between information spaces as aimed by DP1. For example, when a user selects a digital representation of a physical document in the augmented File Explorer user interface, the position of the physical document has to be indicated in the physical space. Finally, the User Interface Management component takes care of the synchronisation of user interface states. As mentioned before, cross-media PIM user interfaces provide support for the three re-finding cues. When a user is interacting with, for example, contextual document metadata in one user interface such as an augmentation of the File Explorer and they switch to another user interface (e.g. augmented physical filing cabinet) then the last user interface should be aware that contextual information of the document should be shown.

## 4.6 SUMMARY

We presented technical requirements which have been derived from the three design principles of cross-media PIM user interfaces as well as the user-centric design requirements introduced in Chapter 3. These technical requirements formed the base for the proposed conceptual system architecture which should enable the design of cross-media PIM user interfaces. In order to develop the described architecture's components, the conceptual system architecture has been decomposed into three research units where the results of each research unit contributes to the achievement of one or more technical requirements.

# Part II

# ENABLING THE DESIGN OF CROSS-MEDIA PIM SOLUTIONS

# 5

# TRACKING DOCUMENTS AND THEIR STRUCTURES

In this chapter, we focus on the design and implementation of an extensible tracking middleware which enables the tracking of temporal and spatial metadata of digital as well as physical documents and their organisational structures. The contributions of the developed framework to the overall system architecture are highlighted in red in Figure 5.1. First, we extended the OC2 framework with the necessary entities for storing which document has been tracked by which tracking setup (i.e. tracking plug-in). Additionally, the OC2 framework has been extended to also include knowledge about the composition of the organisational structures. Furthermore, we implemented the tracking middleware with a plug-and-play mechanism as previously discussed in Chapter 4. The tracking middleware with the OC2 framework extensions have been implemented in the presented DocTr framework. Note that we use the term *tracking setup* for a particular setup including hardware as well as software components which enable the tracking of physical and digital documents within a specific physical area or application. For example, a tracking setup might consist of a camera which is mounted above the desk in combination with some computer vision software or it can be a bookcase where individual books have been RFID tagged. Similarly, in the digital information space, a tracking setup might just be a small software component which interfaces with the Windows32 API to know the exact path of a digital document stored in the File Explorer.

We first elaborate on the used methodology which is followed by an introduction of the architecture of the presented DocTr framework. Next, the implementation of the main components of the architecture are discussed. This is followed by illustrating how developers and end users can make use of the DocTr framework as well as how third-

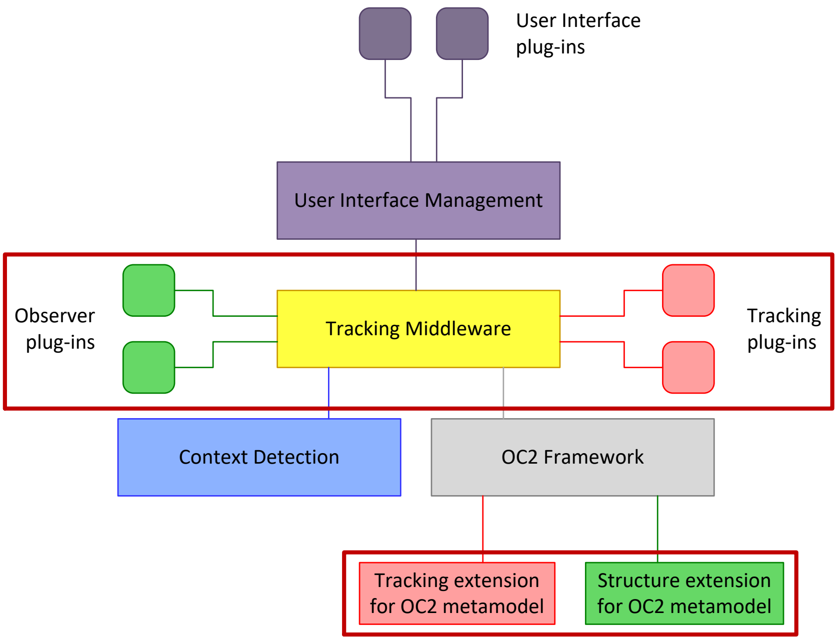



Figure 5.1.: DocTr's contributions to the overall system architecture

party applications can request the tracked metadata of documents and organisational structures. Finally, we present a technical evaluation of the DocTr framework.

## 5.1 METHODOLOGY

In order to develop the DocTr framework, we have used the *Design Science Research Methodology (DSRM)* defined by Peffers et al. [86]. The methodology consist of problem identification, defining the objectives for the solution, design and development of the solution, demonstration, evaluation and communication.

- **Problem identification:** Typical office and digital environments commonly include multiple organisational structures where digital and physical documents naturally flow between these structures.

However, existing solutions focus on tracking positional data of documents within single organisational structures based on dedicated technologies or digital application interfaces. In addition, there is a lack of research which unifies the tracked metadata of digital and physical documents as well as any data management is typically delegated to the application layer. This leads to fragmented and inconsistent tracking data when multiple tracking setups are used. Therefore, we have developed the DocTr framework.

- **Defining objectives for the solution:** According to the description of the work package presented in Section 4.3, the DocTr framework main objectives are related to enabling tracking functionality for documents and organisational structures within and across the digital and physical information spaces. Moreover, we have to provide extensibility (R5), manage different unique identifiers of digital and physical documents (R6) as well as enable the tracking of metadata of organisational structures (R1) and the flow of documents between organisational structures (R2). Note that these requirements originate from our previously mentioned user studies in Chapter 3 and the derived technical requirements in Chapter 4.

- **Design and development of the solution:** In order to achieve the given objectives, we designed and implemented the DocTr framework. In the remaining of this chapter, we elaborate on the architecture of the DocTr framework, the extensions made to the OC2 framework, how we manage the multiple unique identifiers and how error-prone tracking has been reduced by the DocTr framework.

- **Demonstration:** We demonstrate the functionality of the presented DocTr framework at various levels. Moreover, we illustrate how developers can use the DocTr framework to unify tracking setups and how end users can browse tracked metadata of digital and physical documents. Additionally, we elaborate on how third-party applications can make use of the DocTr functionality. Finally, we demonstrate the overall functionality of the DocTr framework by implementing various tracking setups such as tracking setups that monitor piles on a desk by using computer vision techniques as well as tags and follow the movement of ring binders by making use of RFID technology.

- **Evaluation:** The demonstration setup has been used to conduct a technical evaluation which investigates how well DocTr handles error-prone tracking setups and manages multiple unique identifiers of digital and physical documents. Note that since the DocTr framework is a middleware, its accuracy depends on the accuracy of the used tracking setups. Therefore, the accuracy has not been taken into account during the evaluation.

- **Communication:** The DocTr framework has been published at the 8th ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS 2016) [105].

We now present the DocTr framework which addresses the described objectives as well as the corresponding demonstrators and evaluation. Note that parts of this chapter are based on the paper presented at EICS 2016 [105].

## 5.2 THE DOCTR FRAMEWORK

The DocTr framework forms a middleware between multiple tracking setups and third-party applications that want to make use of a document's tracked metadata. There is a clear separation of concerns between the responsibilities of different tracking setups and the DocTr framework. The responsibility of a tracking setup is to determine the unique identifier of a traced digital or physical document. In addition, a tracking setup responsible for providing DocTr the digital representation of a monitored physical document. A representation could, for example, consist of an image of the physical document or a custom icon. Note that when a document has been tracked by multiple tracking setups (i.e. each providing a digital representation of the physical document), DocTr will use the first received representation in the GUI. Since DocTr keeps the other digital representations in the backend, third-party solutions can request all of them when needed. However, when no digital representation has been received of the monitored physical document, DocTr will use a default icon. These digital representations are then made available to third-party applications. When a tracking setup detects a physical document, it sends the document's unique identifier together with some derived metadata such as the document's position to DocTr. DocTr then checks whether the physical document is moving between organisational structures or whether it is a new physical document. In the case that this process does not lead to a clear result, the user is asked for clarification.

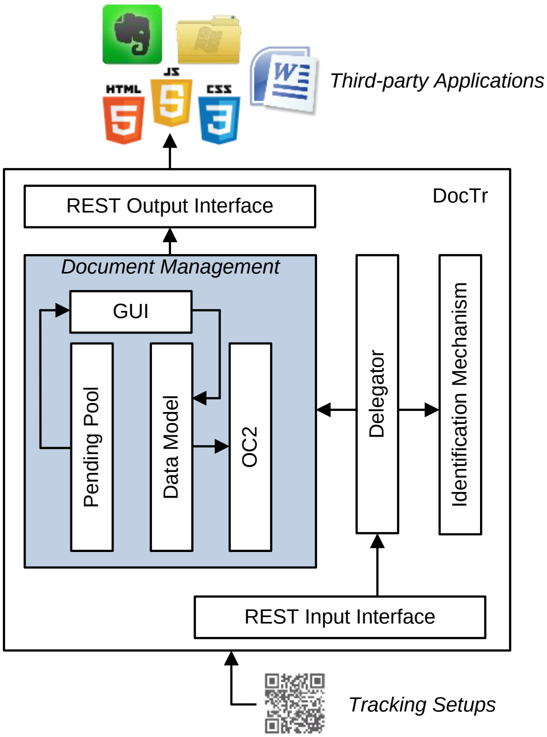



Figure 5.2.: DocTr architecture overview with the OC2 framework has been integrated as a data storage backend

The implementation of DocTr is based on a client-server architecture with the DocTr server using the component-based software architecture shown in Figure 5.2. Tracking setups can communicate with DocTr via the REST Input Interface while third-party applications can use the REST Output Interface to query metadata about tracked digital and physical documents and their organisational structures. The Document Management component is responsible for the management of the tracked contextual (i.e. determined by CMT), temporal and spatial metadata of documents as well as organisational structures while the Identification Mechanism is in charge of comparing unique document identifiers. The Document Management component includes the OC2 PIM framework [102] in order to fulfil the last technical requirement (R8). We have extended the OC2 data model to support different categories of organisational structures and enable the storage of custom metadata. When DocTr cannot automatically determine whether a tracked entity has been moved, the corresponding document is forwarded to the Pending Pool component. Documents and organisational structures that have been added to the Pending Pool wait for further user feedback such as a confirmation that a document has been moved if DocTr is not sure about its position or if a document has been placed in a non-trackable area. The communication between the different components is coordinated by the Delegator component. Finally, the DocTr framework has been implemented in Java and uses a GlassFish[1] server together with the Atmosphere[2] framework providing an implementation of the JAX-RS recommendation for RESTful web services. In the following sections, we further elaborate on the individual DocTr components and their implementation.

### 5.2.1 *DocTr Data Model and PIM Integration*

In order to support organisational structures, custom metadata and multiple unique identifiers, we have slightly extended the OC2 data model. An Entity-Relationship (ER) representation of the resulting extended data model with the shaded entities that have already been defined in OC2 is shown in Figure 5.3. In the OC2 model, objects can represent digital or physical objects as indicated with a disjoint constraint between the subclasses of `Object`. This allows us to create an instance of a digital and physical object for each digital and physical document. As mentioned before, a tracking setup is responsible for providing unique identifiers for its tracked documents and documents can be tracked by various tracking setups. Therefore, an `Object` can be associated with multiple `Tracking Setups`. We further introduced `Tracking Properties` on the association

1 `https://glassfish.java.net`
2 `https://github.com/Atmosphere`

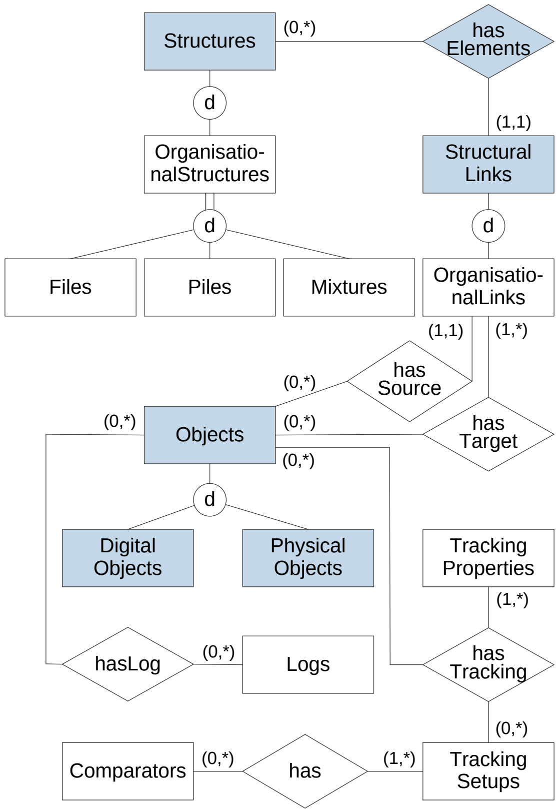



Figure 5.3.: DocTr data model with highlighted OC2 entities

between an object and a specific tracking setup in order to store custom metadata of a specific document for a specific tracking setup. Since the unique identifier of a document depends on the tracking setups used for monitoring the document, it is stored as a tracking property. Therefore, each association between an object and a specific tracking setup must have at least one tracking property. The one-to-many constraints on the relationship between tracking properties and tracking setups enables the reuse of unique document identifiers across tracking setups. For example, a physical document might be identified by a fiducial marker which can of course be used by two or more tracking setups. Furthermore, it is necessary to manage multiple unique identifiers of documents with different formats. Therefore, we introduced the `Comparators` entity set. For a specific format, a comparator component will compare a given detected identifier against a set of unique identifiers. In order to allow the identification mechanism to compare unique identifiers, each tracking setup has to specify the appropriate comparator for its tracked documents. This modelling approach enables the storage of data needed for the positional tracking of digital and physical documents.

In addition to the need of document spatial metadata, we have to enable the storage of temporal and custom metadata. Therefore, an object can be assigned some `Log` entity instances. A log instance takes the format of `(TimeStamp, Transactions)` where a transaction consists of a key (e.g. action) and its value. Note that in contrast to other tracking applications, a timestamp can have multiple transactions. This enables applications to decompose an action in sub-actions. For example, applications can store one log entry when a document is removed from an organisational structure with the key 'remove' having a value 'pile1' and at the same time with a key 'byUser' with the name of the user who moved the document.

Besides the tracking of documents, it is required to also track similar metadata about the organisational structures. Organisational structures are stored as an organisational link with an `Object` entity as source and an ordered set of `Object` entities as target. The source object represents the organisational structure such as a pile while the targets of the organisational link represent the documents included in the organisational structure. This way of modelling an organisational link implies that the model's tracking extensions can also be applied to organisational structures. This is necessary since organisational structures are also dynamic in their position. A ring binder can, for example, be moved from a shelf to a desk. In addition, organisational structures have to be categorised in one of the three organisational structure types (R1). Since the RSL data model already provides the notion of structures, we have introduced the `OrganisationalStructure` as a subclass of the `Structure` entity. In its turn, the `OrganisationalStructure` entity is subclassified into the `File`, `Pile` and `Mixture` organisational structures. The disjoint constraint indicates that an organisational structure can only take the form of one type of organisational structure. Finally, an organisational link has to be associated with an organisational structure.

### 5.2.2 *Identification Mechanism*

When a tracking setup sends the unique identifier and the derived temporal or spatial metadata of a detected document to DocTr, we will first have to identify the OC2 `Object` that represents the detected document based on the received unique identifier. Therefore, the `Delegator` first fetches the corresponding `Comparator` from the database that has been associated with the tracking setup at the moment that the tracking setup has been registered. Next, the `Delegator` queries the data model for all existing unique identifiers (i.e. stored as `Tracking Properties`) which format can be handled by the given comparator. This set of unique identifiers and their associated OC2 `Objects` as well as the received unique identifier and the corresponding `Comparator` instance are given to the identification mechanism. The identification mechanism will invoke the `compare(listExistingIDs, receivedID)` method of the `Comparator` interface shown in Listing 5.1. The first parameter is the set of unique identifiers and their associated OC2 `Objects` in the form of a map. The map has the OC2 `Objects` as key entries where each key is associated with a list of `java.lang.Objects` representing the OC2 `Object`'s unique identifier values. The second parameter is the received unique identifier (i.e. wrapped in an `java.lang.Object` instance) which has to be compared against the list of unique identifiers given for every key in the map. If there is a match, the associated OC2 `Object` of the unique identifier will be returned to the `Delegator`. The `Delegator` will request the document management component to update the necessary associations of the OC2 `Object` with regard to the received temporal and spatial metadata (e.g. adding a `Log` instance for the received temporal metadata). However, in case that the `compare()` method cannot find a match for the received unique identifier in the set of existing unique identifiers, the received unique identifier will be returned to the `Delegator`. Thereby, the `Delegator` will add the received unique identifier to the pending pool where the user has the opportunity to manually associate the received unique identifier with a previously tracked document or indicate that it concerns a new document.

DocTr currently supports comparators for SIFT features, String comparators based on the Levenshtein distance as well as exact matching of Strings and Integers. From our experience, these are the most commonly used formats in existing tracking setups. However, custom comparators can be provided by implementing the `compare()` method of the `Comparator` interface.

Listing 5.1: Comparator interface

```
interface Comparator

public java.lang.Object compare(
  listExistingIDs Map<oc2.Object, List<java.lang.Object>>,
  receivedID java.lang.Object);
```

### 5.2.3 *Pending Pool for User Feedback*

The `Pending Pool` component manages documents which could not be resolved by the identification mechanism. This can, for example, happen when a physical document that is uniquely identified by a tag is moved to another tracking setup which uses SIFT features for identification. Similarly, organisational structures such as a ring binder could, for instance, be identified via an RFID tag when placed on a desk while computer vision techniques might be used to detect the ring binder's label when stored on a shelf. Furthermore, a user can always throw away a document, give it to somebody else or place it in an unmonitored area.

Our solution for addressing undetected documents is inspired by context-aware applications which aim to involve the user in order to decrease the vulnerability to errors and increase user satisfaction [9]. We developed an end-user application where users can provide the necessary input to resolve issues with documents in the pending pool.

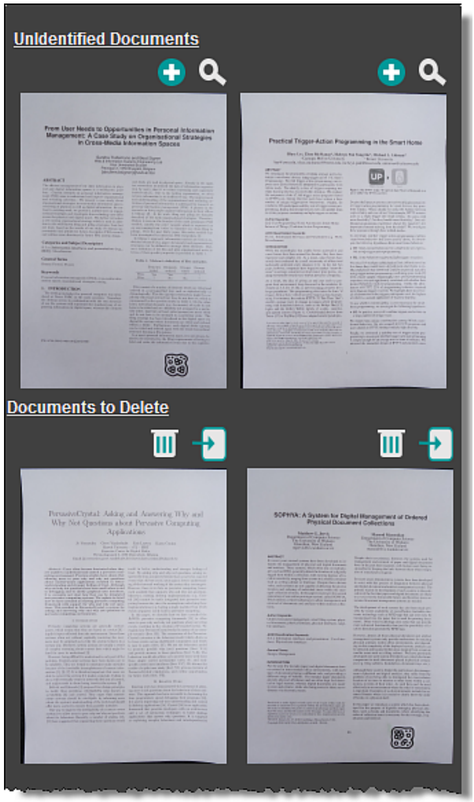



Figure 5.4.: DocTr sidebar

When a document is added to the pending pool, the user will get a notification via the system tray. The system tray allows quick access to the DocTr sidebar shown in Figure 5.4. Unidentified digital and physical documents are added to the sidebar's upper part. A user can click on the green plus button to indicate that the document is new or use the search button to open the exploratory GUI shown in Figure 5.5. After selecting a document, a user can inform DocTr that it is the same document as the one shown in the sidebar by selecting the `Same As` context menu. The pending pool will then add the new unique identifier to the list of known unique identifiers of the selected document. When a document

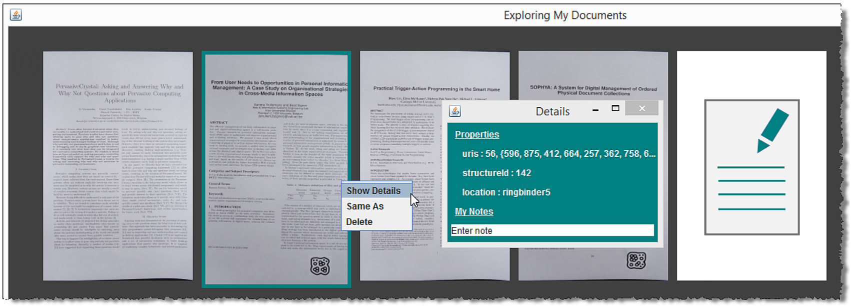



Figure 5.5.: DocTr exploratory graphical user interface

is removed from an organisational structure and cannot be allocated to another structure, the document is added to the lower part of the sidebar. A user can choose to delete a document (bin) or to add it to another organisational structure. In case that a document should be assigned to another organisational structure, a popup is shown with all organisational structures containing non-identified documents as well as an area where a user can indicate whether a document has been placed outside of a monitoring area or given to someone else. This metadata will be stored in the document's log. Depending on a user's actions, the pending pool will notify the Delegator component to proceed with the required actions such as adding the physical or digital object instance as a target to the organisational link at a certain index of the given organisational structure.

The DocTr framework also offers an exploratory graphical user interface to navigate through the tracked documents and explore their metadata as shown in Figure 5.5. The exploratory GUI shows the documents in a list. If the document is a physical document the digital representation is shown. In case that the tracking setup did not provide a digital representation, a default icon is used. Users can right click on a document in order to request a document's details. The details panel includes the document's tracking properties such as the unique identifiers (`uris`) but also to which organisational structure (`structureId`) the document belongs. Furthermore, users can add annotations to the document in the note section.

## 5.3 HOW TO USE DOCTR

On the server side, we have foreseen two REST interfaces which can be used by client applications to communicate with DocTr as illustrated earlier in Figure 5.2. While the REST Input Interface is designed for tracking setups which add information about documents in their monitored area, the REST Output Interface is used by third-party applications intending to use metadata about tracked documents and organisational structures.

### 5.3.1 *Input Interface for Tracking Setups*

The REST Input Interface includes endpoints for creating new documents as well as organisational structures and for updating metadata values. First, a tracking setup has to register itself and define which comparator is required for its unique identifiers. In the simplest case, a tracking setup only monitors documents without any organisational structure. When a document's unique identifier (i.e. tag number or SIFT features) is detected in this simple case, the tracking setup sends the unique identifier together with additional log entries to DocTr by calling the corresponding endpoint for updating a document. The Delegator component requests the identification mechanism for the OC2 object of the received unique identifier and checks whether the detected document is already waiting for allocation in the pending pool. Next, the Delegator updates the data model with the new knowledge. When a tracking setup monitors an organisational structure, it has to create this structure in DocTr in an initialisation phase and keep the returned identifier of the initialised organisational structure. When detecting a change to the organisational structure, the tracking setup has to notify DocTr by sending a JSON string including the identifier of the organisational structure, the index where the document has to be added and the derived unique identifier of the tracked document. When a document is removed from an organisational structure or monitoring area, the tracking setup has to call the remove endpoint with the identifier of the organisational structure and the document identifier. As previously mentioned, the document will be added to the pending pool if no other tracking setup recognised the removed document. In practice, we could, for example, use the

SOPHYA [51] framework for tracking physical folders in bookcases. In addition, a user might have a monitored area around their laptop on a desk which identifies physical documents based on fiducial markers as done in DocuDesk [35]. In their daily activities, a user might move a physical document from an augmented SOPHYA folder to their workplace around the laptop. DocuDesk and SOPHYA would only have to deal with four DocTr endpoints including the registration, the initialisation of organisational structures, as well as the adding and removal of documents. Since DocTr helps integrating different tracking setups, an interactive office application no longer has to be based on a proprietary platform for managing different tracking setups.

### 5.3.2 *Output Interface for Third-Party Applications*

While the REST Input Interface is used by tracking setups, the REST Output Interface can be used by third-party applications to query DocTr's data model as well as to listen to updates of the data model. The interface provides endpoints for querying the data model entities and exploring documents of the pending pool. Furthermore, applications can establish a WebSocket connection to be notified when a data model entity has changed its value. A JSON message is sent over the WebSocket connection including the identifier of the entity and the new values such as a new location. For example, an Evernote[3] extension can be developed which listens to DocTr for log updates of paper documents that a user has used in Evernote notes. In addition, Evernote can request the digital representation of paper documents in order to allow users to integrate paper documents in their Evernote notes. Similarly, the digital representation of a paper document can, for example, be used in the File Explorer in order that users can organise paper and digital documents in a unified way. Third-party applications only have to process the received messages which contain the identifier of the document or organisational structure as well as any additional metadata.

3 `https://evernote.com`

## 5.4 PRELIMINARY TECHNICAL EVALUATION

Due to the fact that the accuracy of DocTr depends on the accuracy of the used tracking setups and the implementation of the comparators, an evaluation of DocTr as a middleware is only possible by integrating it in larger applications with a significant amount of different tracking setups. Therefore, we have chosen for a preliminary evaluation which investigates how well DocTr can handle error-prone tracking setups and how the behaviour changes over time when multiple unique identifiers are given to a document. Since the unique identifiers of physical documents can be significantly more complex and error-prone such as the SIFT algorithm than digital documents which are mostly identified by their path, we have used physical documents for the presented evaluation. The results show that even with error-prone tracking, the accuracy can be improved by letting users provide feedback about similar documents in the pending pool.

### 5.4.1 *Methodology*

We have implemented four tracking setups, shown in Figure 5.6, to determine the accuracy of DocTr when moving paper documents across organisational structures with the same or different document identifier formats as well as for the movement of the organisational structures themselves. The first two tracking setups ① and ② monitor piles based on the SIFT algorithm. The third tracking setup ③ tracks the adding and removal of paper documents from ring binders on a desk surface by using the ReacTIVision framework. Finally, the last tracking setup ④ monitors a bookcase with ring binders which has been augmented with RFID technology.

The procedure of the evaluation consist of four tasks where each task $T_i$ consists of one or more subtasks $T_i^R$ which remove a document from a tracking setup and one or more subtasks $T_i^A$ adding the same document to another tracking setup. An overview of the performed tasks is given in Table 5.1 and discussed below. At the beginning of the evaluation, documents have been added to the pile monitored by the first tracking setup ①. We did not involve users in this evaluation since the

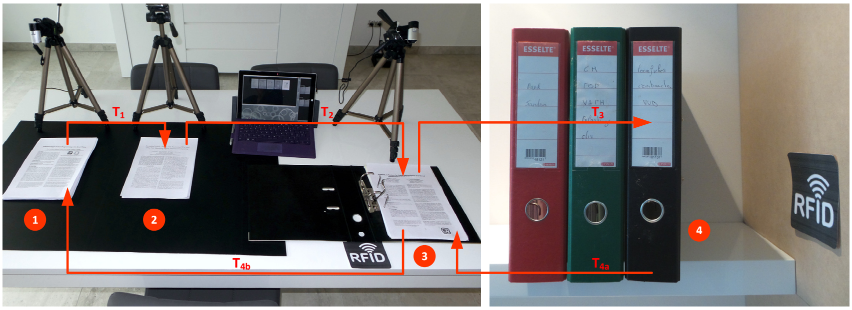



Figure 5.6.: Evaluation setup

evaluation's purpose was to determine how DocTr can handle multiple unique identifiers as well as error-prone tracking setups.

**Task 1** ($T_1$). *Moving a paper document between organisational structures with the same document identifier format.*

Tracking setups ① and ② both track physical documents based on the SIFT algorithm. We have used the SIFT Keypoint Detector Java library[4] to extract the SIFT features of documents. Furthermore, the two tracking setups use different cameras. In this first task $T_1$ of our evaluation, documents are removed from the pile of tracking setup ① via $T_1^R$ and added to the pile of tracking setup ② via $T_1^A$.

**Task 2** ($T_2$). *Moving a paper document between organisational structures with different document identifier formats.*

In order to evaluate the fact that a physical document can have more than one unique identifier across tracking setups, $T_2^R$ moves the documents from the pile in tracking setup ② and $T_2^A$ adds them to a ring binder monitored by tracking setup ③. Tracking setup ③ consists of RFID tagged ring binders, an RFID reader placed underneath the desk and a camera installed above the desk. When physical documents are moved from the pile of tracking setup ②, we added a fiducial marker to them. In the case a ring binder is placed within the range of the RFID reader, the application starts listening to the reacTIVision framework in order to detect fiducial markers. Finally, if any document is detected, the

4 `http://www.cs.ubc.ca/~lowe/keypoints`

application requests DocTr to add the detected document to the ring binder organisational structure.

**Task 3** ($T_3$). *Moving an organisational structure.*

Since organisational structures can also be tracked by the DocTr framework, in task $T_3$ the ring binder is removed from the desk via $T_3^R$ and added to the bookcase via $T_3^A$. Each shelf of the bookcase contains an RFID reader and before placing the ring binder on a shelf, it has to be scanned by the associated RFID reader.

**Task 4** ($T_4$). *Moving documents back to the first tracking setup.*

In the last task, we move the documents of the ring binder back to the pile of tracking setup ①. As part of task $T_4$, $T_{4a}^R$ first move the ring binder from the bookcase shelf and $T_{4a}^A$ added it to the desk in tracking setup ③. The documents are then removed from the ring binder via $T_{4b}^R$ and added to the pile by $T_{4b}^A$.

| **Task** | | **Actions** |
|---|---|---|
| $T_1$ | $T_1^R$ | Documents are removed from the pile in setup ① |
| | $T_1^A$ | Documents are added to the pile in setup ② |
| $T_2$ | $T_2^R$ | Documents are removed from the pile in setup ② |
| | $T_2^A$ | Documents are added to a ring binder in setup ③ |
| $T_3$ | $T_3^R$ | The ring binder is removed from the desk in setup ③ |
| | $T_3^A$ | The ring binder is added to the bookcase in setup ④ |
| $T_4$ | $T_{4a}^R$ | The ring binder is removed from the bookcase in setup ④ |
| | $T_{4a}^A$ | The ring binder is added to the desk in setup ③ |
| | $T_{4b}^R$ | Documents are removed from the ring binder in setup ③ |
| | $T_{4a}^A$ | Documents are added to the pile in setup ① |

Table 5.1.: Overview of the evaluation tasks

The procedure consisting of task $T_1$ to $T_4$ was repeated five times in order to present more accurate results. Furthermore, a total of 55 printed research papers from various conferences and journals were used. We decided to use research papers due to their high similarity when processed by computer vision techniques which represented a challenge for the used document identification techniques.

### 5.4.2 *Results*

As described in the methodology, in each task physical documents are first removed from an organisational structure and then added to another organisational structure and the two subtasks are monitored by different tracking setups. The results of the five iterations for the four described tasks $T_1$ to $T_4$ are shown in Figure 5.7. For each iteration and task $T_i$, we measured the amount of positively identified documents when removing them via subtask $T_i^R$ from on organisational structure and adding them to another organisational structure via $T_i^A$.

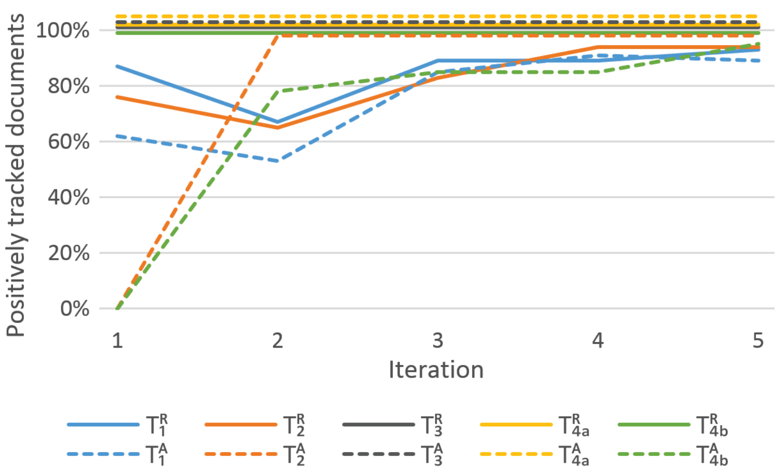



Figure 5.7.: Percentage of positively identified documents

When having a look at the results of $T_1^R$, $T_1^A$ and $T_2^R$, we can observe that in the first two iterations the identification mechanism could not accurately match the given unique identifiers based on SIFT. This might be caused by the error proneness of the used SIFT algorithm and the small threshold value defined in the SIFT comparator. In each iteration, the new unique SIFT identifier is manually added to non-recognised documents via the DocTr sidebar. DocTr then adds the new unique identifier to the existing set of identifiers for the given document which implies that in the next iteration more unique document identifiers of the document can be used during the identification process. As a result, the matching accuracy improved over the five iterations without reaching 100%. This might be caused by the fact that the two SIFT tracking setups both define their SIFT feature matrices which might slightly diverge from each other. Note that the amount of unmatched physical documents were caused by the inaccuracy of the used SIFT algorithm in the two tracking setups and by using research papers which looked very similar. It is known that the SIFT algorithm is not ideal for identifying similar documents [67] but DocTr can help to improve the accuracy of error-prone tracking setups via user feedback. In addition, in $T_2$ documents are removed from the pile of tracking setup ② via subtask $T_2^R$ and added to the ring binder ③ via subtask $T_2^A$. During the first iteration of $T_2$, documents were augmented with a tag before being added to the ring binder and the DocTr sidebar has been used to allocate the tag number to the document. As a consequence, none of the documents could be identified during this first iteration. The results of $T_2^A$ further show that documents are always positively identified after the first iteration. Furthermore, removing the ring binder from the desk via subtask $T_3^R$, adding it to the shelf via $T_3^A$ and placing it back to the desk via subtasks $T_{4a}^R$ and $T_{4a}^A$ is always positively tracked. Finally, the removal of documents from the ring binder via $T_{4b}^R$ has also been tracked accurately. Nevertheless, when adding the documents back to the first pile of tracking setup ① via $T_{4b}^A$, no documents were identified by the SIFT comparator since tags have been added to the documents in the first iteration of $T_2^A$.

## 5.5 CONCLUSION

We have introduced DocTr, a unifying framework for tracking temporal and spatial metadata of digital and physical documents as well as organisational structures across different tracking setups. This metadata is made available to third-party applications via DocTr's REST Interface. Furthermore, the results of our preliminary technical evaluation shows that the accuracy of document identification can be significantly increased by asking users minimal feedback. Finally, DocTr provides extensibility at the tracking level by using a plug-in mechanism for tracking setups, manages successfully the different unique identifiers of documents, enables besides the tracking of metadata of digital and physical documents also the tracking of organisational structures and DocTr can monitor the flow of documents between organisational structures.

# 6

# CONTEXT-AWARENESS OF DOCUMENT INTERACTIONS

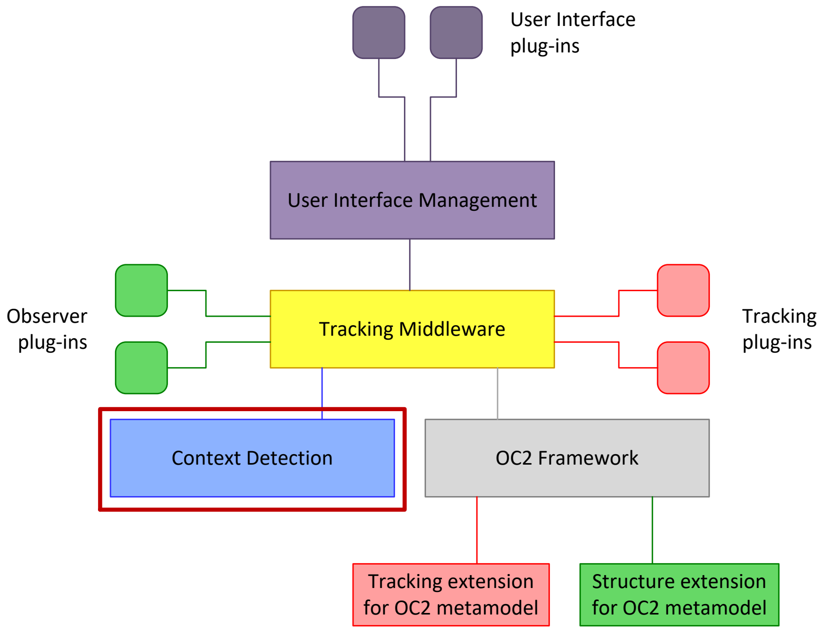



Figure 6.1.: WP2 contributions to the overall system architecture.

While Chapter 5 addressed the tracking of a document's metadata related to the temporal and spatial re-finding cues, in this chapter we focus on enabling the tracking of metadata necessary to support the contextual re-finding cue. The detection of a document's contextual metadata is facilitated by the Context Modelling Toolkit (CMT). The contribution of this chapter's work to the overall system architecture is highlighted in red in Figure 6.1. We will first discuss the used methodology which is followed by an elaboration on the contribution of CMT in the field of Ubiquitous Computing. The remainder of this chapter presents the technical details of CMT and we provide some use cases in order to show the main advantages of using CMT for context modelling. Note that parts of the following sections are based on the paper presented at EICS 2017 [104].

## 6.1 METHODOLOGY

Similar as to the DocTr framework, we have used the *Design Science Research Methodology (DSRM)* defined by Peffers et al. [86]. The methodology consists of problem identification, defining the objectives for the solution, design and development of the solution, demonstration, evaluation and communication.

- **Problem identification:** We have observed that the contextual cue is significantly applied during re-finding activities. However, deriving contextual information from document interactions is not easy since users have significant variations in their daily tasks. In order to achieve end-user satisfaction, users are being involved in the context modelling phase. While we have witnessed a raise of visual programming tools for context-aware applications based on simple *"IF this THEN that"* rules, due to their limited expressiveness these tools are normally not well-suited to define complex context rules.

- **Defining objectives for the solution:** As a solution to the given problem, we propose a unified multi-layered context modelling approach distinguishing between end users, expert users and programmers. By providing a seamless transition between the different user levels and the reuse of situations defined by the end user, we aim to provide end user tools that allow them to model daily tasks.

- **Design and development of the solution:** We present the Context Modelling Toolkit (CMT) as a solution to enable users to model sophisticated rules. CMT consists of the necessary context modelling concepts to support the multi-layered context modelling approach and offers a rule-based context processing engine. We further provide the corresponding graphical end-user and expert-user interfaces.

- **Demonstration:** We implemented three demonstrators which illustrate the advantages of CMT. We used CMT to model a smart home environment (which is used throughout this chapter as a use case), monitor elderly people at home and, in the context of this dissertation, to monitor interactions with documents and their organisational structures.
- **Evaluation:** The CMT framework has been technically validated by the implementation of the aforementioned demonstrators. Furthermore, CMT has been used by Master's thesis students who investigated the sharing of context and situation rules [112], used CMT to enable context-aware augmented user interfaces for office environments [27] and provide context-aware functionality in Outlook [84].
- **Communication:** The Context Modelling Toolkit has been published at the First International Workshop on Smart Ecosystems cReation by Visual dEsign (SERVE) co-located with the International Working Conference on Advanced Visual Interfaces (AVI 2016) and at the 8th ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS 2017) [104].

## 6.2 CONTRIBUTION TO UBIQUITOUS COMPUTING

Besides the contribution of CMT to enabling the design of cross-media PIM user interfaces, we also contribute to the field of Ubiquitous Computing since CMT is designed in a generic and extensible way. Therefore, CMT can be used to model user-centric context in any smart environment as illustrated in the following sections.

For decades context-aware frameworks have been developed to facilitate the development of context-aware applications in various domains such as in smart homes, mobile applications and recommendation systems. Context-aware frameworks often include support for context modelling and reasoning. Various software approaches have been used. The SOCAM [43] framework is an example of an ontology-based context-aware framework. Developers define an ontology including possible situations and their description by using the OWL ontology language. Unfortunately, an ontology-based approach is not ideal for dynamic context modelling. Changing the ontology at runtime introduces possible issues with respect to conflicts and ontology integrity. Dynamic context modelling can be supported by taking an object-oriented approach such as done in the Java Context Aware Framework (JCAF) [5] which has a service-oriented architecture. Context services are components that notify other services or client applications about which situation they have detected and can be added or removed at runtime. Although this feature is necessary for dynamically modelling context, JCAF forwards the reasoning of context rules to the application layer. This has the consequence that whenever users want to change a rule's behaviour, client applications have to be redeployed. Further, context rules are spread over various applications which might lead to issues concerning conflict management and inconsistent application behaviour across client applications. In order to overcome these issues, JCOOLS [85] integrates JCAF with the Drools inference engine. Although JCOOLS offers a good software basis for our proposed multi-layered context modelling approach, they lack support for end users and expert users. Finally, the most well-known and used context-aware framework in the Human-Computer Interaction (HCI) community is the Context Toolkit by Dey et al. [28]. The Context Toolkit is based on a component-based software design where components are represented by so-called widgets. Each widget processes information, from low-level data input to higher-level abstract context information (i.e. detected situations). Similar to JCAF, the context reasoning is pushed to the application layer. In order to allow for intelligibility and control over context rules, Dey and Newberger extended the Context Toolkit with a middleware that includes the concept of situations [30]. Whenever all of a situation's widgets are active, the situation will invoke an action of the context services listening to it. However, the reuse of situations is impossible since situations can only have widgets as input.

In the research fields of ubiquitous computing and end-user programming, plenty of research has been done on visual end-user programming tools. Due to our focus on the *"IF situation THEN action"* paradigm, we only include rule-based user interfaces. The jigsaw editor [50] is a very simple puzzle-based tool to configure smart homes. The puzzle blocks are provided by developers and users cannot change the behaviour of a situation (e.g. what should be triggered to make the situation true). Due to the intentional simplicity of the tool, its expressiveness is limited. In contrast, iCAP [31] provides a wide range of functionality for context modelling. Users can easily combine context cues to define a situation. For example, person 'Joe' can be combined with location 'Kitchen' to indicate that Joe has to be in the kitchen. These situations are then associated with desired actions. In addition, users can define new facts such as a new person who's name is Bob. More recent work follows a template approach in order to facilitate the construction of rules. For example, in AppsGate [26] the programmer creates templates for rules where the end user can fill in desired devices and parameters. A similar approach is taken in the work of Ghiani et al. [41] where the presented authoring tool enables programmers, domain experts and end users to define rules for context-dependent cross-device user interfaces.

Besides the basic rule-based user interfaces, new approaches to digitally program smart homes or objects have been introduced recently. CAMP [107] steps back from the rule-based approach by allowing users to declare application behaviour in natural language. The tool includes a limited set of magnetic labels with each label defining a concept such as a room or person. Although CAMP is a nice programming paradigm, in the context of context modelling it has its limitations and it would be hard to define all possible context elements (situations and actions) beforehand. A more radical approach in end-user context modelling is the introduction of the *programming by example* concept. Systems such as PiP [22], aCAPpella [29] and GALLAG strip [74] allow users to define situations by physically performing the activity. Finally, Reality Editor [49] uses augmented reality to add behaviour to objects. Users can use the mobile phone as a see-through lens in order to, for example, add digital behaviour to a lamp.

Based on our investigation of related work, we can conclude that there is a broad spectrum of context modelling tools ranging from context-aware frameworks for developers to end-user tools. Recently, Ur et al. [111] aimed for the development of tools that provide some distinct degree of complexity since end users are very different in their abilities to define *"IF situation THEN action"* rules. However, existing context modelling tools commonly allow users to customise parameters

| Application | Situations defined by | Rules defined by | Reusable situations |
|---|---|---|---|
| SOCAM [43] | programmer | programmer | - |
| ICAF [5] | programmer | programmer | - |
| JCOOLS [85] | programmer | programmer | +/- |
| Context Toolkit [30] | programmer and customisation by user | programmer | - |
| Jigsaw [50] | programmer | user | - |
| ICAP [31] | programmer and customisation by user | user | - |
| CAMP [107] | programmer | user | - |
| AppsGate [26] | programmer and customisation by user | user | - |
| Ghiani et al. [41] | programmer and customisation by user | programmer, domain expert and user | - |

Table 6.1.: Comparison of related work based on the type of user who is responsible to define new situations or rules and the potential reuse of situations which is either not possible (-) or possible but not foreseen (+/-)

of situations which are pre-defined by programmers and rules are mostly defined by the programmer or the user as shown in Table 6.1. We can also observe that the work of Ghiani et al. [41] identified the need for three types of users in the design of context rules as proposed by Ur et al. [111]. Nevertheless, similar to related context modelling tools, they do not foresee the possibility that users can define and reuse custom situations. In contrast, our Context Modelling Toolkit enables programmers, expert users as well as end users to create situations and rules at their level of expertise and allows all three types of users to reuse each other situations in order to simplify the definition of the IF-side of a rule.

## 6.3 THE CONTEXT MODELLING TOOLKIT

The Context Modelling Toolkit (CMT) enables a seamless transition between the different levels of expertise of *programmers* who are experienced with low-level programming, *expert users* with little or no programming experience as well as *end users* without any programming knowledge. Programmers are responsible for providing interfaces with devices and applications since this step requires some programming skills. Expert users can create rule templates which only requires some basic knowledge about data types and declarative concepts. Finally, end users can fill in rule templates with data instances such as a specific device but do not have to be familiar with the internal logic of a rule. A user can switch between the three user types if they have the necessary expertise for a particular level. CMT further enables the creation of new situations at runtime and fosters the reuse of the custom situations at all three user levels.

The CMT framework is implemented as a rule-based client-server architecture. While the server side takes care of the context reasoning, clients feed the server with context data such as facts (i.e. persistent data such as a person), situations (i.e. temporal data such as the current temperature) and actions which can be invoked when situations are detected. Additionally, custom-defined situations from end users are also sent to the server by the graphical end-user context modelling user interface. Based on this context data, programmers, expert users and end users can create context rules which will be evaluated by the server every time new sensor events are received. When context rules become valid, the assigned actions are invoked.

In order to facilitate the end-user context modelling process, we foresee the option to let end users create new situations such as 'cooking' by creating so-called *situation rules* which take the form of *"IF situations THEN new situation"*. In its simplest form, the IF side of a situation rule can just be a combination of context events. Nevertheless, we also allow users to reuse newly defined situations on the IF side. For example, the situation rule *"IF Person is Bob and Location is kitchen THEN Bob is in the kitchen"* takes `Person:Bob` and `Location:kitchen` as context data on the IF side to define a new situation. This new situation can then, for example, be reused in the situation rule *"IF Bob is in the kitchen AND stove is on THEN Bob is cooking"* or in a context rule such as *"IF Bob is in* *the kitchen THEN turn on radio"*. In contrast to previous work, with our approach users do not have to re-define a situation every time they want to use it in a different situation or context rule.

We use the concept of *templates* to further simplify the definition of situation and context rules. A template serves as a skeleton for rules as illustrated in Figure 6.2. The IF-side can consist of multiple situations or logical functions where a function evaluates some logical statements and returns the result. In a CMT context, functions can only return boolean values. For example, a function might evaluate whether two persons are at the same location. Situations and functions might take various parameters such as a person and a room which have a specified type (e.g. `Person` and `Location`). In contrast to the definition of a rule, a template does not specify a specific instance (e.g. `Person:Bob`) for a parameter of a given type. The binding to a specific instance is only done when the template is used to create a concrete situation or context rule. In order to know which object types are needed by the template, it contains a `To Fill In` part listing the required object types. The listed object types are connected to the corresponding input variables of situations or functions on the IF-side. When a user fills in a template, they only have to provide the concrete instances of the listed object types such as `Person:Bob`. Finally, the THEN-side of a template defines the new situation.

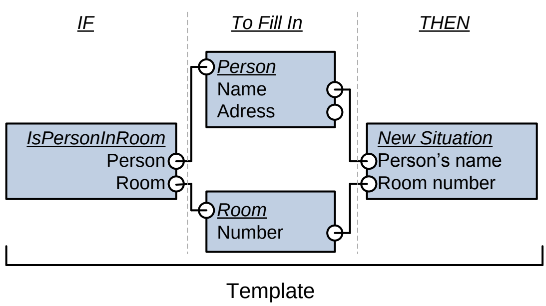



Figure 6.2.: `personIsAtLocation` template

Since situations can have parameters, expert users can add these to the new situation by defining which properties of a template's required object types have to be forwarded to the new situation. For example, in

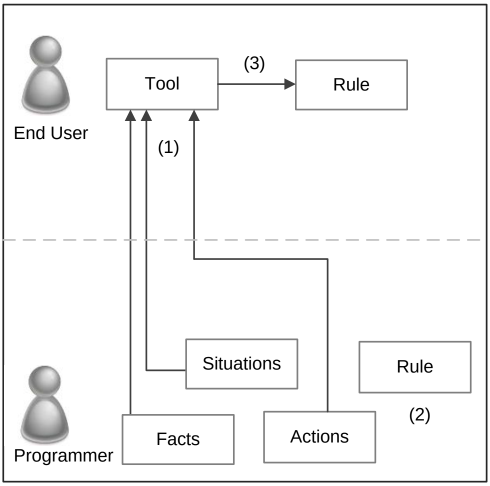



Figure 6.3.: Existing context modelling approaches

Figure 6.2 the person's name and the room number are forwarded to the new situation. After a template has been created, it can be used to define situation and context rules. For example, the situation rule *"IF Person is Bob and Location is kitchen THEN Bob is in the kitchen"* could be created by using the `PersonIsAtLocation` template shown in Figure 6.2 and by simply filling in the variables `Person:Bob` and `Location:kitchen` followed by naming the new situation as *"Bob is in the kitchen"*. The same template could be used to define that Bob is in the living room.

## 6.4 A MULTI-LAYERED CONTEXT MODELLING APPROACH

The situation rules and templates were introduced to support users with different levels of expertise as proposed by Ur et al. [111]. In existing systems, programmers are often responsible for providing contextual data in terms of facts and situations as well as possible actions (1) which an end user can then apply to construct simple context rules (3) as illustrated in Figure 6.3. Facts such as `Person:Bob` and actions like turning on the lights are usually defined once by the programmer. In contrast, sensors or third-party applications are programmed to send

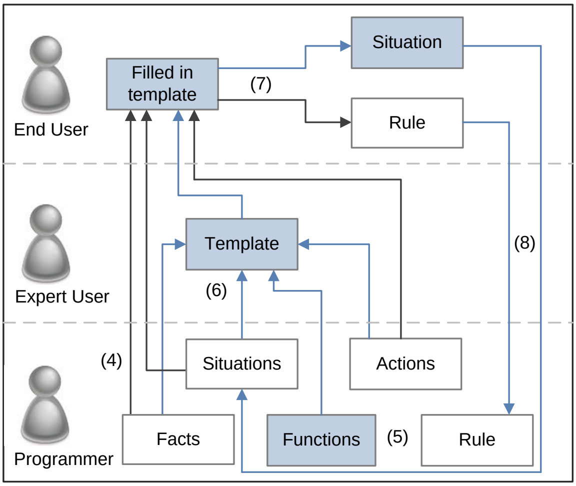



Figure 6.4.: Multi-layered CMT approach

situation events such as the current temperature in a stream of data. Furthermore, in context modelling solutions without end-user control, programmers also implement the desired context rules (2).

In contrast to existing work, we extended the previous model with an intermediate layer for expert users and integrated the notion of custom and reusable situations. In addition, rules and situations created by end users flow back to the programmer layer to provide a seamless transition between the three layers as shown in Figure 6.4. As mentioned previously, each layer is designed for users with a specific profile. Similar to existing systems, in our multi-layered context modelling approach shown in Figure 6.4, programmers are responsible to provide facts, situation events and actions to the end user (4). In order to allow expert users to create templates, they also have to provide functions (5) and the previously mentioned context data to the expert user (6). End users can fill in templates by using the provided context data. The completed templates can define new situation and context rules (7). New situations are made available at the programmer layer in order that they can be reused on the expert and end-user layer (8). Similarly, custom context rules flow from the end-user layer back to the programmer layer. These custom rules are then usable by programmers or other applications to reason over. Our approach does not only provide end users control in terms of context modelling but also with respect to the balance between automation and context modelling control. For example, some users might only design new context rules or situations when they have a real need for specific functionality while leaving simple context modelling to a programmer. Other users might design their entire context-aware environment, such as their smart home, themselves.

## 6.5 implementation of the context modelling toolkit

In order to have a unified representation of the context data sent by sensors, applications or end users, we have designed the CMT data model shown in Figure 6.5. The CMT data model simply models the previously discussed templates, functions and contextual data. Items such as facts and context input require a certain object type (e.g. `Person`) which can have multiple properties (e.g. a person's name). Contextual input can either consist of events or situations. While events are context input object types pre-defined by a programmer, situations are defined via a situation rule by the end user or programmer. As elaborated earlier, templates have an IF side and a THEN side. The IF side might include context input and functions. In turn, functions can have contextual input or facts as parameters. In addition, these parameters can refer to one of the properties of a contextual input or fact object type. Furthermore, a template can be used to construct situation or context rules. In the case of a situation rule, the THEN side of the template must include a new situation. On the other hand, in a context rule actions can be added to the THEN side.

The Context Modelling Toolkit is designed as a client-server architecture implemented in Java. As shown in Figure 6.6, CMT has a db4o[1] database backend and uses Drools 6[2] as rule engine. We currently support the Java Remote-Method Invocation (RMI) and REST communication protocols. Since the two protocols require a different data exchange format (i.e. RMI shares classpaths and REST might use JSON), the CMT server contains the CMT-RMI and CMT-REST components. These compon-

1 `http://www.mono-project.com/archived/db4o`
2 `http://docs.jboss.org/drools/release/6.1.0.Final/drools-docs/html_single/`

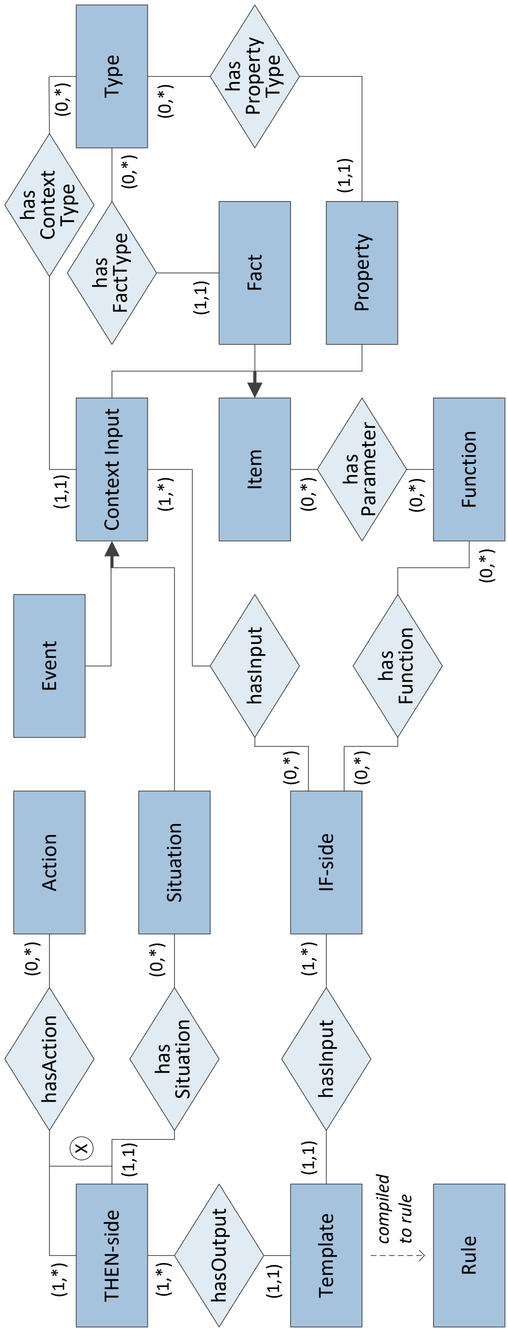



Figure 6.5.: CMT data model

ents translate their input to CMT data model entities and generate the required output format when data is sent to clients.

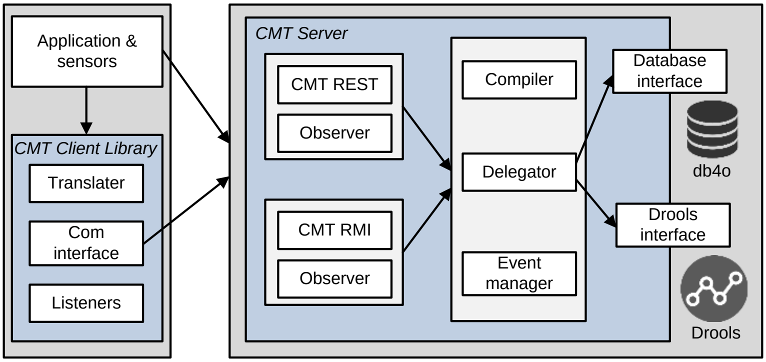



Figure 6.6.: CMT architecture

In order that clients can reuse each other's context model and the server can reason over the clients' context models, clients have to follow the steps highlighted in Table 6.2. First, a client has to register the object types of facts, situations and actions which they use in their context model. Depending on the used communication protocol, the CMT-RMI or CMT-REST component will translate the incoming data to `Fact`, `Event` or `Action` objects which are defined by the CMT data model. Next, the `Compiler` component will check whether the object type already exists, based on the given type name. In case the object type exists, the client is notified via an error. Since Drools requires compiled Java classes of the registered object types, the Compiler component will compile these classes and add them to the classpath at runtime. The server then makes these object types available to all other clients which can reuse these context elements in available functions, templates and rules.

After registration, clients can add instances of the registered object types to the server. In case of the REST version, a new class instance will be created and the appropriate field values will be set to the values given in the incoming JSON format. The CMT-REST and CMT-RMI components will forward the received fact or event object to the `Delegator` component. In case the object is a fact, the `Delegator` component sends it to the `Database Interface` which inserts it into db4o. The `Delegator`

| Client | | Server |
|---|---|---|
| 1) **register** object types of facts, events and actions | → | makes types available |
| 2) **add** facts, situations, functions and templates | → | makes objects available and evaluates rules |
| 3) **fill in** template | → | compiles and evaluates rules |
| 4) **listens** | ← | notifies state changes |

Table 6.2.: Steps performed by a CMT client

further sends both, facts and events, to the `Drools Interface` where they are inserted in Drools and rules are re-evaluated.

When using the REST interface to add templates and functions to the CMT server, the JSON format is again translated to `Template` and `Function` objects which are compiled and made available to Drools as well as to the clients. Furthermore, templates are stored in the database. When a filled in template is received, it is compiled to the Drool's specific DRL rule format[3]. This new rule is then inserted into the Drools knowledge base and all rules are re-evaluated. Note that our implementation of the rule compilation is a complex mechanism which takes into account the full first order logic and provides in depth error handling for client applications.

Clients can also listen to server state changes. State changes include changes in the data model such as added facts or situations but also actions which are triggered or situations which became valid. The CMT-RMI and CMT-REST `Listener` components are in charge of providing the appropriate mechanism to notify their clients. For example, the REST version implements a publish-subscribe pattern where clients can subscribe to various event types via a WebSocket connection. When

3 https://docs.jboss.org/drools/release/5.2.0.Final/drools-expert-docs/html/ch05.html

using RMI, clients can implement the `CMTEventListener` interface which includes event notifications of, for example, new situations that are added to the CMT server.

Finally, there needs to be a conflict management mechanism for actions associated with situations. Moreover, in the case that actions are associated with a situation in a context rule and the same situation is used in a situation rule, the actions will be invoked when the situation becomes valid—in addition the actions related to the situation defined by the situation rule are also invoked. For example, if the situation 'meeting' is re-used in a 'department meeting' situation rule and has been used in a context rule with actions, it might be desired to only invoke actions linked to the department meeting and not those of the more generic meeting situation. To handle such a use case, the `Event Manager` component is introduced. When situations become valid, the `Event Manager` is notified. It catches the triggered action events from Drools. Before notifying clients to invoke these actions, the Event Manager checks whether there is no other valid situation triggered by the previous situation. When this recursive process stops, clients are notified with the last valid situation and its corresponding actions.

## 6.6 CONTEXT MODELLING TOOLKIT USAGE

The multi-layered context modelling approach requires different forms of interaction with the CMT server. While programmers can directly use the CMT REST interface, expert users and end users need a graphical user interface.

### 6.6.1 *Programmer*

We currently provide a CMT Client library in Java for the easy development of Java and Android applications making use of CMT. When a client wants to add an application-specific class type to the CMT server (e.g. a class `Person` in Java) in order that end users can use this type of context data in their context modelling, it has to be translated to a `Fact` instance of our CMT data model. In order to facilitate this conversion, methods are provided by the CMT Client library. For example, a programmer just has to provide the class instance and the field name which represents the unique identifier of a fact when registering the fact type as shown on line 1 in Listing 6.1. In order to send a fact instance to the CMT server, the appropriate method can be called and the Java object representing the fact (e.g. Person instance with name Bob as unique identifier) can simply be given as parameter as shown on line 2 in Listing 6.1. It is the responsibility of the `Transformer` component included in the CMT Client library to do the necessary conversions to the CMT data model whereas the `COM Interface` provides abstractions for the REST calls to the CMT server. Finally, Java applications can implement listeners, available in the `Listeners` component, which catch specific events sent by the server. Note that it is not mandatory to use the CMT Client library. Clients can also communicate with the CMT server via REST calls as illustrated in Listing 6.2.

Listing 6.1: Registering and adding a fact by using the CMT library.

```
1 registerFacttypeInCMT (Person.class,"name");
2 addFactInCMT(personBob);
```

Listing 6.2: Registering and adding a fact by using the REST interface.

```
{"className":<Person>, "uriField": <name>,
    "fields":[{"fieldName":<name>,
    "type":<String>},{"fieldName":<age>, "type":<Integer>}]}
{"className":<Person>, "uriField": <Bob>,
    "fields":[{"fieldName":<age>, "fieldValue":"55"}]}
```

### 6.6.2 *End-User and Expert-User Interface*

In order to support end-user context modelling and allow expert users to create templates, we propose two initial versions of our graphical user interfaces. Note that in the future these GUIs will be enhanced with more advanced interaction techniques such as *programming by example* where users are able to record a situation which is then translated to context rules by CMT.

Both graphical user interfaces are implemented in one JavaFX application which uses the CMT Client library in combination with the REST CMT server version. Due to our aim of a seamless transition between levels of expertise, the application has an end-user and an expert-user mode. Users can freely switch between these two modes

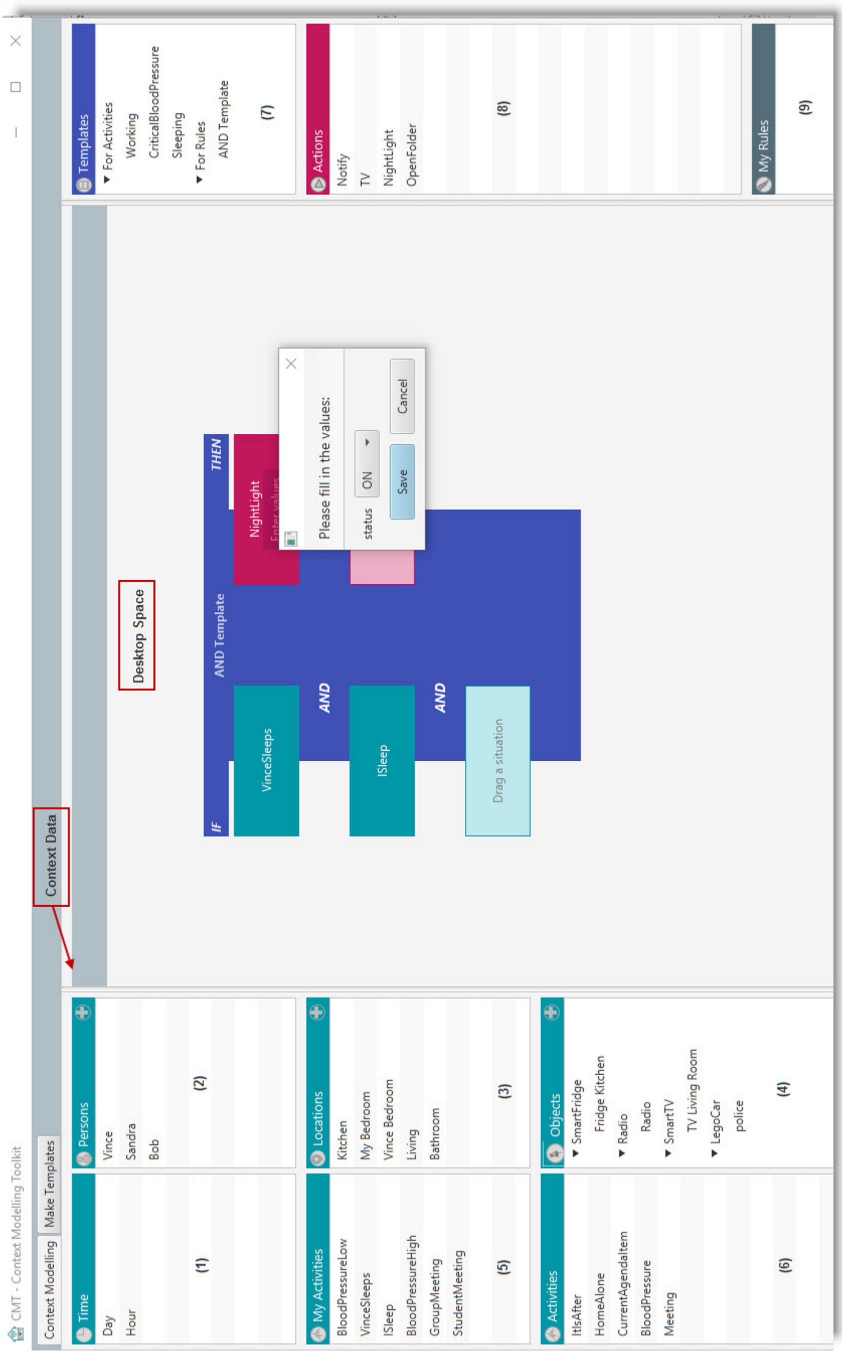



Figure 6.7.: Main view including the context data on the sides and a desktop space where users can create or fill in a template

based on their skills or needs. The application consists of a desktop space in the centre surrounded by context data boxes as shown in Figure 6.7. The left-hand side of the general graphical user interface view contains the context data boxes with time-based events (1), persons (2), locations (3), objects (4), custom situations (5) and situations provided by developers (6). We distinguish between time-based events, persons, locations and other objects because, as mentioned by Dey [31], users often think in these distinctive dimensions. The context data elements in these boxes can be mapped back to CMT data model instances of `Fact` and `Context Input`. Furthermore, the right-hand side contains the available templates (7), actions (8) and the defined context rules (9). When the user works in expert mode, a box with the available functions is added to the right-hand side.

In order to define new context rules in the end-user mode, end users can use the 'AND template' which takes situations or time-based events as input on the IF-side as shown in Figure 6.7. In this template, the logical operator is limited to AND operations in order to keep it simple. However, it is up to the programmer or expert user to develop more advanced templates to, for example, support more complex logical statements. The THEN side can be populated with actions with the corresponding properties. In the example shown in Figure 6.7, user Sandra models a context rule stating that *"IF Vince (her child) sleeps AND she sleeps THEN the small night light has to be turned on"*. This rule makes sense for her personal household since Vince is afraid of the dark and requires a night light to sleep but in order to save energy, she only wants to turn it on when she is also asleep. In order to create this context rule, she previously defined the situations which track whenever Vince or herself sleep. She can now also reuse the *"Vince sleeps"* situation in another context rule, for example, *"IF Vince sleeps THEN set the TV volume to 20"*.

In order to define a new situation, end users use templates. Expert users can create these templates by switching to the expert mode where the template authoring view is shown in the desktop space as illustrated in Figure 6.8. Experts can drag functions or events (i.e. situations or time-based events) to the IF side (1). They can choose logical operators such as AND, OR, NOT between added events and functions (2). As defined by the CMT data model, context input and functions may require certain parameters. These parameters are listed below the header which includes the function's name or event type (3). Since the template does

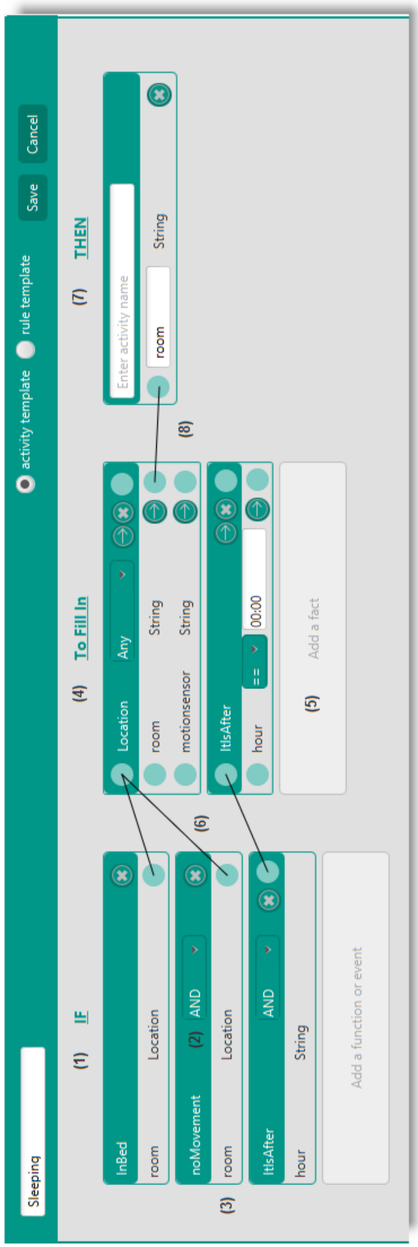



Figure 6.8.: Template authoring view

not define the value of these parameters but only the required object type, the template view includes the "To Fill In" space (4). In this section, the required object types needed to complete the template are listed. Expert users can drag and drop context data object types from the context data boxes provided on the left-hand side of the main view to the empty placeholder (5). In order to keep a reference between these object types and the event or function's parameters, links can be created between a parameter and the associated object type (6). Finally, the new situation defined on the THEN-side (7) can be given properties by selecting them from the listed object types which have to be filled in (8). After a template has been defined, it is sent to the CMT server and made available to all other client applications. In our example, the template *"Sleeping"* is created as shown in Figure 6.8. The expert user Sandra defined sleeping as being in bed and there cannot be any movement in the bedroom as well as it has to be later than a specified time. Note that Sandra has added the *"no movement"* in the bedroom event since it can, for example, occur that Vince is playing in his bed which would fire an *"in bed"* event. In this example, being in bed is a predefined situation with a bedroom as parameter and is provided by a programmer. The *"in bed"* event will be send every time movement is detected by a motion sensor that has been placed under the pillow. The *"no movement"* event also takes a room as parameter and is fired when the motion detector of the specified room is in idle state. Finally, the *"later than time"* event is fired when the current time is later than the specified time. Our expert user drags a `Location` object type to the `To Fill In` list and connects the `Location` type to the corresponding parameters of the *"in bed"* and *"no movement"* events. Finally, the user leaves the `Location` to state `ANY` (9) without filling in a specific room and does not specify a time for the *"later than time"* event. These values have to be entered by the end user when applying the template. In the case that the expert user defines the value of some of these object types (e.g. by selecting a room instead of `ANY`), the value cannot be changed later by the end user when using the template. Note that also programmers can provide such templates to end users. This can be desired in the context of application-specific logic such as in a fitness or health application.

End users can use the templates to create new situations by dragging a template to the desktop space where the template's end-user view is shown as illustrated in Figure 6.9. The template's IF-side contains the

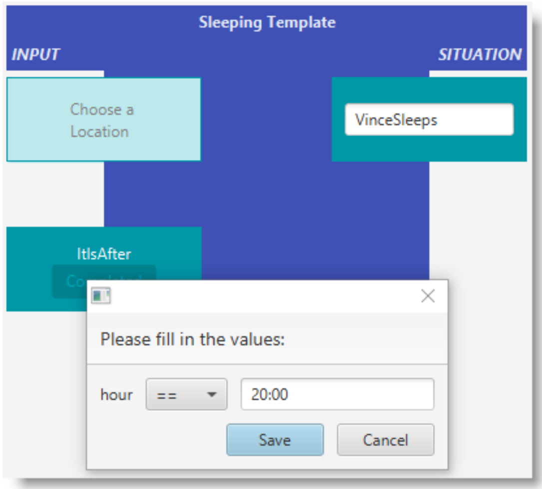



Figure 6.9.: End-user view of a template

placeholders for the required object types defined by the expert user in the `To Fill In` list. When the end user selects a placeholder, they are given a request to select an instance of the required object type or to enter necessary data as shown in Figure 6.9. Finally, when hovering over the template, the logic defined by the expert user will be shown in textual form. In terms of our example, the first placeholder requires an instance of a `Location` while the user has only to enter the desired time in the second placeholder. Now that Sandra has created the *"Sleeping"* template in the expert mode, she can populate it to define the situation where Vince sleeps. She selects *"Vince Bedroom"* as an instance of `Location` for the first placeholder and sets the time value to 8PM. Finally, she labels this new situation as *"Vince Sleeps"*. As mentioned before, the new situations can be reused in other situation or context rules. Note that without reusable situations or templates, the user would have to redefine the logic of *"Vince Sleeps"* every time they would like to use it in new context rules. In addition, our end user can reuse the template to define the situation where they are sleeping by having their bedroom as a location and a later time constraint.

## 6.7 INTEGRATION OF CMT AND DOCTR

In order to identify in which context a document has been manipulated, DocTr makes use of CMT. Moreover, it listens to the user's context changes and associates the user's current context with a document when it is used. In the opposite way, DocTr provides CMT with events related to movements of documents and organisational structures in order that users can use such events in the context modelling phase.

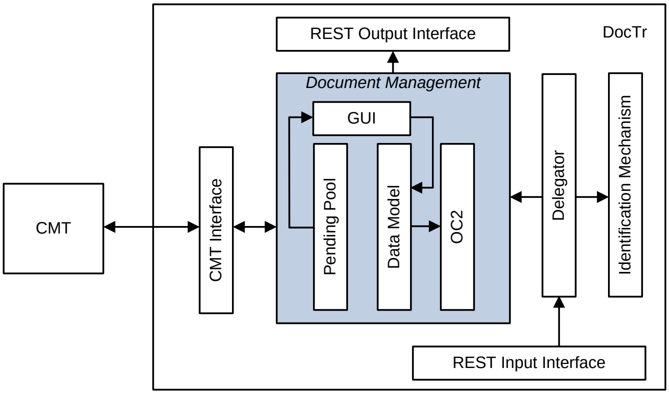



Figure 6.10.: DocTr architecture including the CMT Interface

We have extended DocTr with the `CMT Interface` component which is responsible to communicate with CMT as illustrated in Figure 6.10. It uses the CMT Java Client library to listen to user's context changes by implementing the `CMTEventListener` and to send events related to document manipulations by calling the appropriate methods in the client library interface. When a tracking setup notifies DocTr that a document or organisational structure has been added, moved or removed, the Document Management component will request the user's current context from the `CMT Interface`. The received context from the `CMT Interface` will then be associated with the document or organisational structure in the OC2 framework. Finally, when the Document Management component stores the metadata of a document manipulation in the OC2 framework, it also communicates the particular document manipulation to the CMT Interface. Next, the CMT Interface sends an added, moved or removed event to the CMT framework by calling the `addEvent()` method of the Java CMT client library. Consequently, users can also use document manipulation events in the context modelling of their tasks.

## 6.8 PROOF OF CONCEPT APPLICATIONS

In the following section we provide two implemented use cases which illustrate the advantages of the presented Context Modelling Toolkit. First, we give an example of how the multi-layered modelling approach can be of benefit in the context of monitoring elderly people in their home. Second, we provide a use case in the context of a digital home and illustrate how a user can model a daily task where they make use of documents.

### 6.8.1 *Monitoring Elderly People*

In the current ageing society, technology-enhanced elderly support becomes more important. Various tools, such as fall detection systems or collaborative health platforms, are developed to help healthcare workers in providing the best care. We show how the use of CMT can help to further push the development of such healthcare monitoring tools. For example, custom context rules can be defined by healthcare workers based on the available sensors and specific critical situations. Often critical situations vary across patients, which makes it difficult to develop a solution that fits everybody. Let us assume that a patient or their relatives defined the *"ISleep"* situation as introduced earlier. This situation can then be used in the following context rules:

```
IF stove == on AND ISleep
  THEN Notify(central, "alarm")
IF BloodPressureLow AND NOT ISleep
  THEN Notify(nurse, "blood pressure low")
IF BloodPressureHigh AND AloneHome
  THEN Notify(doctor, "critical blood pressure")
```

Note that these rules are highly customised to the subject since other patients might require other actions. For example, when they have a high blood pressure, a reminder to take their medication might have to be given to them. In addition, the critical value that determines when a patient's blood pressure is low/high might differ between individuals. When using our CMT, healthcare workers can use a template which implements the logic of critical blood pressure measurements where they just have to fill in the desired critical values. Furthermore, when a healthcare worker becomes knowledgeable about CMT, they might switch to the expert mode to define a new template for measuring blood pressure with, for example, extra functionality where the heart rate value is also considered.

*Implementation*

The following building blocks are implemented:
**Stove is ON**: situation provided by a programmer of the stove sensor. The stove sends events including its ID and state.
**AloneHome**: fact inserted by a door application in CMT when the healthcare worker leaves the house.
**BloodPressureValue**: situation sent by the blood pressure device including the current value. Note that this event can also be sent by other blood pressure devices as long as they use the same event object type.
**BloodPressureLow/High**: situations defined in the end-user mode by the healthcare worker by using the *"CriticalBloodPressure"* template with patient-specific critical values.
**CriticalBloodPressure template**: template designed by an expert user as having a blood pressure measure event with the pressure value as parameter as well as a function which checks whether the current blood pressure is above a certain threshold.

### 6.8.2 *Context-awareness of Document Interactions*

Environments where also digital applications can form part of the smart ecosystem are so-called Digital Homes. Due to the generic implementation of the CMT framework, any application can add facts, situations, templates or actions to the server. Therefore, the CMT framework can be used as a customisation tool for implicit digital behaviour. For example, a programmer provided Sandra a small application that sends *"LaptopActivity"* situation events to the CMT server every time that mouse or keyboards events are detected on her laptop. Sandra used this situation in forming a context rule that says that *"IF LaptopActivity THEN set door* *display to state busy"*. After a while she gets familiar with CMT and decides to design more customised complex rules by creating her own template. With the previous context rule, she had the issue that the display would also be set to the state busy when she is just checking her emails. Nevertheless, she still wants to have the display's busy state on when she is, for example, writing a research paper but desires the available state when she edits presentation slides of a course. A programmer has created an extension to the Windows File Explorer which monitors which file is accessed and sends a *"WorkingInFolder"* event including the file and the current directory's name. Sandra can use this event in her template design for generalising a working situation since her papers are grouped in a publications folder and course slides in the course folder. She defines that the template has to check whether the *"WorkingInFolder"* event's current directory is the same as the given folder. This template is used to define the situation where she is writing a research paper by entering in the "Publications" folder in the end user view of the previously defined template. She can now also reuse this template in the future to define that she works on a course by filling in the "Course" folder. Finally, she only has to use her newly defined situation of writing a research paper in a context rule which sets the door display to busy state when writing a research paper. Similarly, she can define a *"EditingCourse"* situation in a context rule to set the display state to available. In addition, both custom situations can be reused in the definition of new situations such as *"IF WrittingResearchPaper AND my location is meeting room THEN MeetingAboutPaper"*. This new situation can then be used in a context rule to set her smartphone to silent mode.

*Implementation*

The following building blocks are implemented by a programmer and defined by the end or expert user:
**DesktopActivity**: situation send by a third-party application developed by a programmer. This event is sent to the CMT server when mouse or keyboard activity is detected.
**DoorDisplay**: display listens to the CMT server for *"DoorDisplay"* action invocations with a state as property. States can be busy, available or away.
**WorkingInFolder**: situations defined by a programmer and is sent when the Windows File Explorer extension detects access to a file. The send

situation event includes properties such as the file's name and its directory.

**Working template**: template designed by Sandra in the role of an expert user. The IF side of the template includes the *"WorkingInFolder"* situation event and the "To Fill In" part contains the `Folder` object type provided earlier by a programmer. The `Folder` object type's folder name property is connected to the folder name property of the *"WorkingInFolder"* event located in the IF side.

**WrittingReseachPaper**: custom situation defined by Sandra by using the *"Working"* template in the end user mode. The template is filled with the `Folder` instance that represents the "Publications" folder.

**EditingCourse**: custom situation defined by Sandra. Similar to the above situation, she uses the *"Working"* template in the end user mode, filled with the "Course" folder.

## 6.9 CONCLUSION

The presented Context Modelling Toolkit supports the seamless transition between end users, expert users as well as programmers. It allows the creation of new situations across all three levels of expertise and makes situations reusable in situation and context rules. In order to achieve this functionality, we have introduced the concept of situation rules in the form of "*IF situations THEN new situation*" and templates. Our proposed Context Modelling Toolkit together with its multi-layered conceptual model allows end users to have more advanced control over their smart environments and digital homes. At the same time it offers a balance between automation and manual context modelling.

# Part III

# INFORMING THE DESIGN OF CROSS-MEDIA PIM SOLUTIONS

# 7

# CROSS-MEDIA PIM USER INTERFACES

In the following chapter, we present various proof-of-concept cross-media PIM user interfaces. In order to enable interactions between the user interfaces, we have developed the User Interface Management (UIM) framework as a middleware between the user interfaces and the DocTr framework as illustrated in Figure 7.1. The UIM framework allows user interfaces to share their search states and request another user interface to show the position or metadata of a particular digital or physical document. For example, when a user is exploring digital documents related to a specific context in a graphical user interface, they must be able to switch to another user interface such as a user interface augmenting the physical space showing the related physical documents of the same context. In this way, we can provide users with tools to easily switch between information spaces during re-finding activities.

We start by introducing the UIM framework followed by presenting our developed cross-media PIM user interfaces and the variety of user interactions across these user interfaces. Our first cross-media PIM user interface is the PimVis graphical user interface which allows users to organise and explore digital as well as physical documents. Further, we present our augmented physical filing cabinet which enables users to explore contextual, temporal and spatial relationships between folders by means of a tangible control panel. Finally, we illustrate how cross-media PIM user interfaces can be designed in an ubiquitous manner by presenting extensions for the Windows File Explorer, augmented ring binders and an Android application. Note that all these user interfaces have been developed by using the UIM framework and that various user interactions across the user interfaces have been provided. By designing these proof-of-concept user interfaces, we technically validate the taken

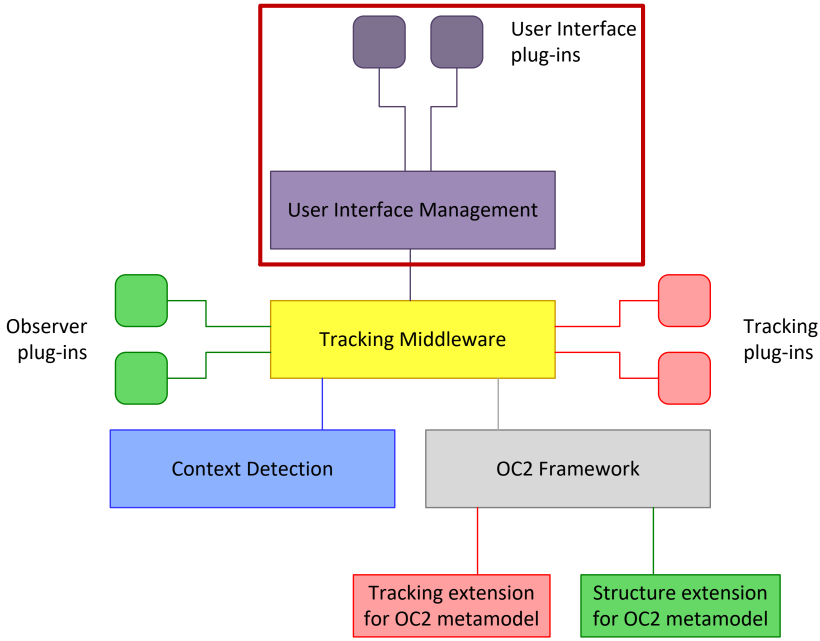



Figure 7.1.: Contribution of the UIM framework to the overall system architecture

approach to the fragmentation of digital and physical documents across tools and information spaces.

## 7.1 ENABLING USER INTERFACE MANAGEMENT

In order to enable the design of cross-media PIM user interfaces, we developed the User Interface Management (UIM) software framework. The UIM framework is a middleware between the various cross-media PIM user interfaces and our DocTr as well as CMT frameworks as illustrated in Figure 7.2. While the underlying frameworks are responsible to track and store contextual, temporal and spatial metadata of digital and physical documents and their organisational structures, the UIM manages the communication and consistency of the states across the multiple cross-media PIM user interfaces. The UIM framework supports three main interactions between user interfaces. First, a user interface can notify UIM that a user selected a digital or physical document or an organisational structure. UIM will query the DocTr framework for the necessary metadata of the selected document which is then sent to all other user interfaces. Second, a user interface can notify the UIM framework about state changes of the re-finding activity. For example, a re-finding activity's state change can be that a user wants to know all documents used within the same day as the selected document instead of the currently shown 'same week' interval. The other user interfaces will be notified by UIM to also update their particular user interface state. Finally, user interfaces can request other user interfaces to find a digital or physical document. In this case, the UIM framework queries the DocTr framework for the positional metadata which includes the knowledge of which user interface is responsible to show the document.

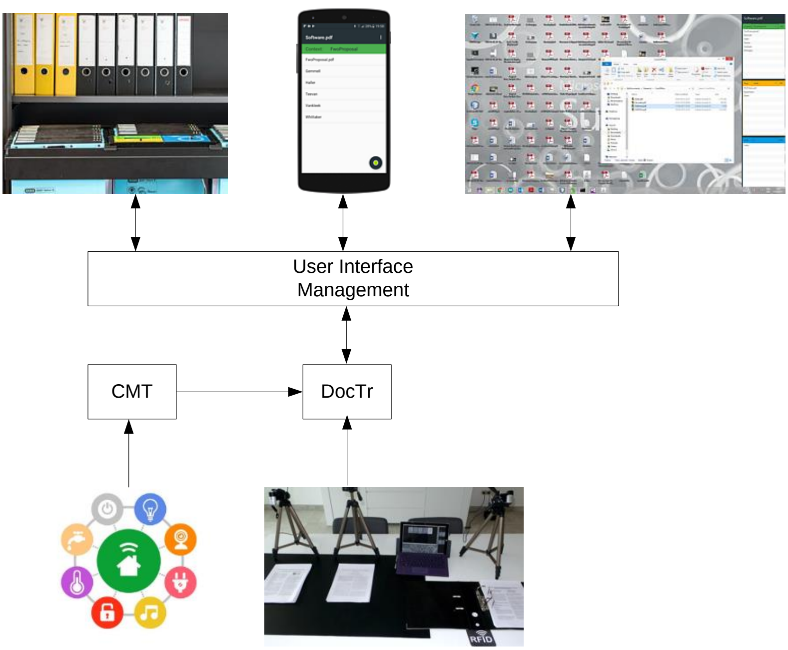



Figure 7.2.: Overview of software components

We used the Model-View-Controller (MVC) as well as the Publish-Subscribe design patterns to enable the mentioned main interactions across user interfaces. Moreover, the UIM framework keeps the model of the state of the re-finding activity and uses DocTr to keep the state of a user's personal information space. User interfaces can subscribe to channels where state changes about the re-finding activity are published by the other user interfaces. We defined a channel for each main interaction (i.e. new document or artefact selection, change of the re-finding activity's state and re-find a specific document). The user interfaces have to publish the changes of the main interactions according to our defined JSON format including the object ID and other related information with regard to the published interaction. Note that the UIM framework does apply some processing before notifying the other user interfaces. For example, querying the DocTr framework for additional information that will be required by the subscribed user interfaces (e.g. in case a new document has been selected). We implemented the UIM framework in Java using a GlassFish[1] server where user interfaces can subscribe to and publish changes of the main interactions by establishing a WebSocket connection. The UIM framework further uses the DocTr client Java library to query the DocTr framework. Note that due to the separation of concerns, the object-driven approach and the simple JSON format to communicate with the UIM framework, other third-party applications such as SOPHYA [51] and SDN [37] can easily be integrated within our augmented environment.

The next sections introduce our proof-of-concept cross-media PIM user interfaces which are making use of the UIM framework. Although we will cover a limited set of possible user interface designs and interactions between user interfaces, the UIM framework's design allows for easy extensions as possibly required by custom office environments.

## 7.2 PIMVIS: DIGITALLY EXPLORING DOCUMENTS AND ARTEFACTS

The first proof-of-concept cross-media PIM user interface is called PimVis. We designed a graphical user interface where users can organise and explore their personal information space including digital and physical documents. PimVis has been implemented as a web-based solution

1 https://glassfish.java.net

which enables the deployment of PimVis on any devices installed with a browser such as the desktop, mobile devices or even a tabletop. We used JavaScript in combination with the D3.js[2] library to implement the PimVis front-end. In this section, we present the different views of our PimVis graphical user interface while the various interactions with the other user interfaces are given in Section 7.5.

The graphical PimVis user interface provides three different views of a user's personal digital and physical documents. The design of the graphical user interface is based on Shneiderman's Visual Information-Seeking Mantra of *"Overview first, zoom and filter, then details-on-demand"* [93]. First, the Context View provides an overview of a user's personal documents in the form of a bubble layout with each bubble representing a context as shown in Figure 7.3. When zooming into a context, PimVis switches to the Document View where documents relevant to the selected context (filter) are visualised in a graph structure as illustrated in Figure 7.4. When selecting a specific document in the Document View, PimVis switches to the Focus View shown in Figure 7.5, in order to provide details-on-demand.

*Context View*

The Context View visualises the documents in their context since we have previously shown in our presented exploratory user study that the context cue is the main re-finding mechanism when re-finding documents in all three types of organisational structures [101]. The different contexts with their related digital as well as physical documents are provided by our DocTr framework which is responsible to map documents to the appropriate context as elaborated previously.

In the Context View, the different contexts are represented by circular nodes (bubbles). This design for displaying contexts has been inspired by the the CAAD system [87] where each bubble represents a context. Nevertheless, the scalability of the CAAD approach is limited since the view might quickly get cluttered when a context is defined for each task. Therefore, we have introduced context hierarchies. Users can group different contexts together to form a more general context. For example, a user can define a context group 'Meetings' which includes the context groups 'Department Meetings' and 'Student Meetings'. In their turn,

2 http://d3js.org

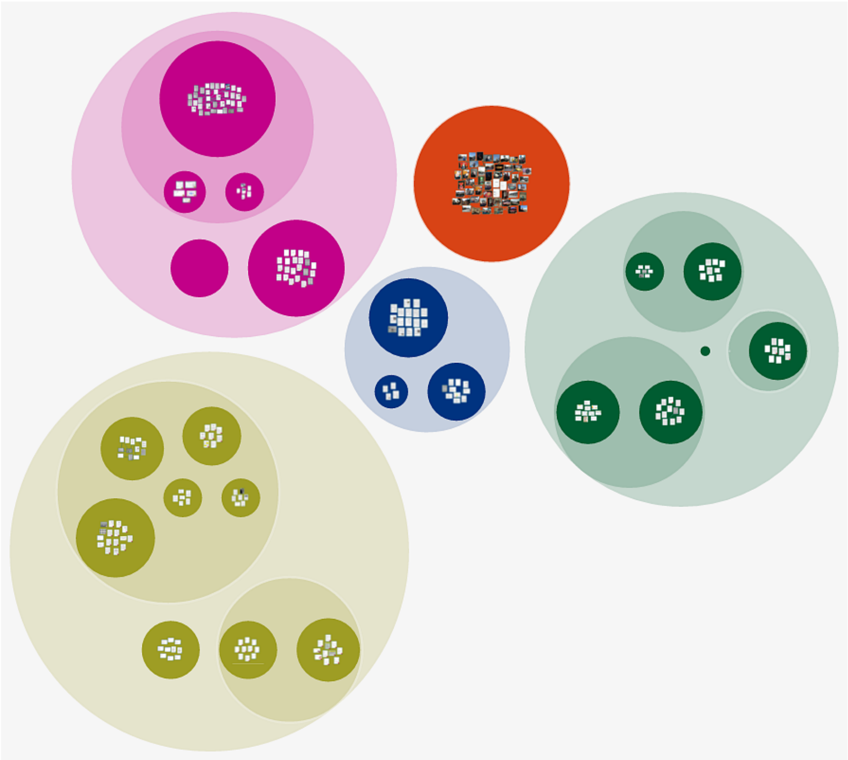


Figure 7.3.: Context View

these sub-context groups can include a context such as 'Meetings with student Bob'. Users can navigate through the context groups by using semantic zooming. Furthermore, each top-level context group has been given a distinctive colour. We have chosen this colour encoding approach instead of showing the name of the context group since otherwise the view might get cluttered. The context and context group names are shown when a user selects a particular context or context group (i.e. details-on-demand). We acknowledge that this implies a learning phase when users start to use PimVis (i.e. remember the contexts' colours). Note that further research is required to find the optimal design choices with regard to the colour encoding and labelling of bubbles. However, participants of the user study where PimVis has been used did not mention significant drawbacks of our initial design approach. Finally, the size of the context bubble represents the number of documents for a given context. When a user zooms into a context group and selects a context, the Document View of the zoomed-in context is shown.

### *Document View*

The design of the Document View is based on the fact that users naturally create associations between information items [63]. The Document View visualises the associations between documents within a certain context in a graph as shown in Figure 7.4. Each node of the graph represents a digital or physical document. The preview of the document and an icon representing its format is used to graphically represent a specific node. The bidirectional associations between documents are represented by the edges of the graph. In our design, we allow users to assign weights to documents and their associations. For example, a user might find a document or an association between documents highly relevant in a particular context. This relevancy is represented by the darkness and thickness of the edges between nodes. Additionally, a document can be given a weight to indicate its relevancy for a particular context. This relevancy is shown to the user by the darkness and thickness of the node's border.

Documents can be explored via different facets. The temporal metadata of all documents (i.e. given by the DocTr framework) is indicated on a timeline at the bottom of the graph. Users can select a time interval by sliding the handles. The graph automatically highlights the documents which have been created or used during the selected time interval. This interaction provides users with support for the temporal re-finding cue. The control panel at the right-hand side of the graph can be hidden/shown via the control panel button and allows users to filter based on additional facets. The first tab of the control panel contains a search box with auto complete functionality for re-finding documents based on their name. In the case that a requested document is found, it is highlighted in the graph. The next control panel tab shows a tag cloud. By selecting a tag in the tag cloud, all documents in the graph containing the tag are highlighted. The following tab offers a context explorer. After selecting a context, PimVis highlights all documents in the graph with some relevancy for the selected context. The type filter tab can be used

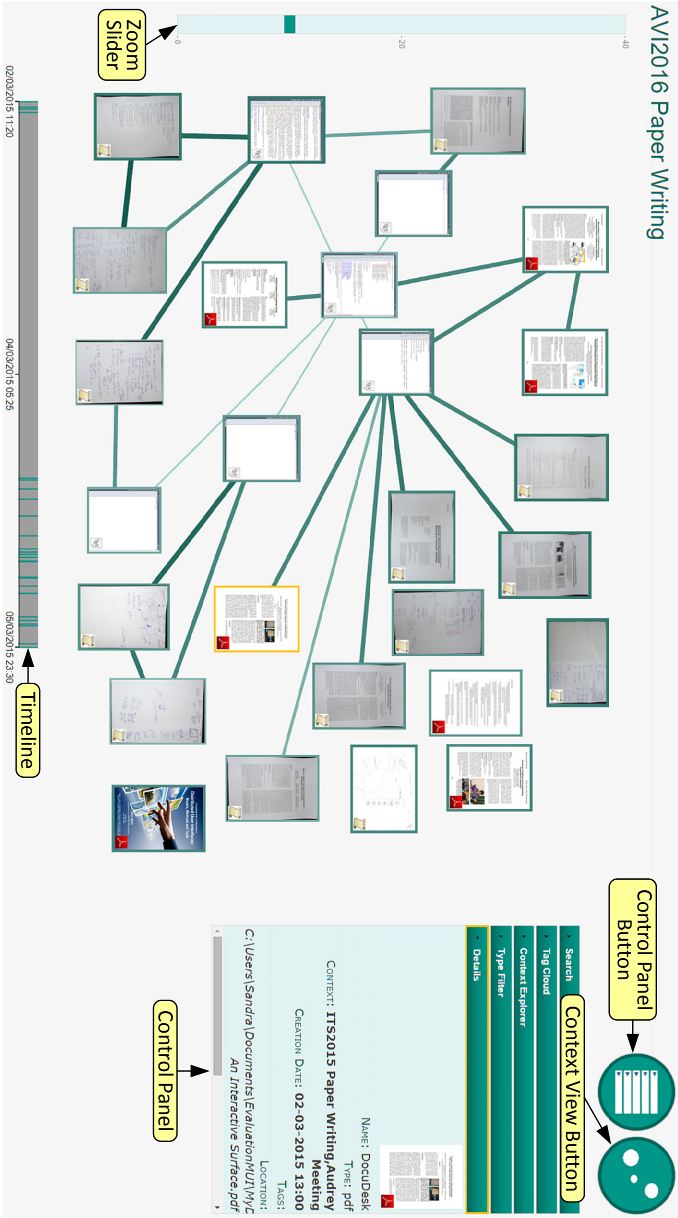



Figure 7.4.: Document View

to filter the elements of the graph based on different document formats such as PDF or docx but also filter all physical documents. The different document formats are represented by thumbnails which are arranged in a grid layout in the type filter tab. The user can tap a thumbnail to highlight all the corresponding documents. Finally, the details tab provides some details about the selected document, including its name, the creation data, assigned tags, relevant contexts and the location of the document. The Document View can be zoomed by using the zoom slider on the left-hand side of the user interface or by using a double tap gesture on a specific document. Once the user zooms into a document, it is shown in the Focus View. In order to go back to the Context View, a user can always tap the Context View button in the upper right corner.

*Focus View*

The Focus View shown in Figure 7.5 provides a detailed view of a document and shows all associated documents within and across contexts. In addition, the detail tab of the control panel is shown with the previously mentioned information. The Focus View also allows users to re-find a document in the digital or physical space. When a user presses the re-find button represented by a magnifying glass, the UIM framework will notify the user interface that is responsible to show the document's position. We will elaborate on these interactions in Section 7.5.

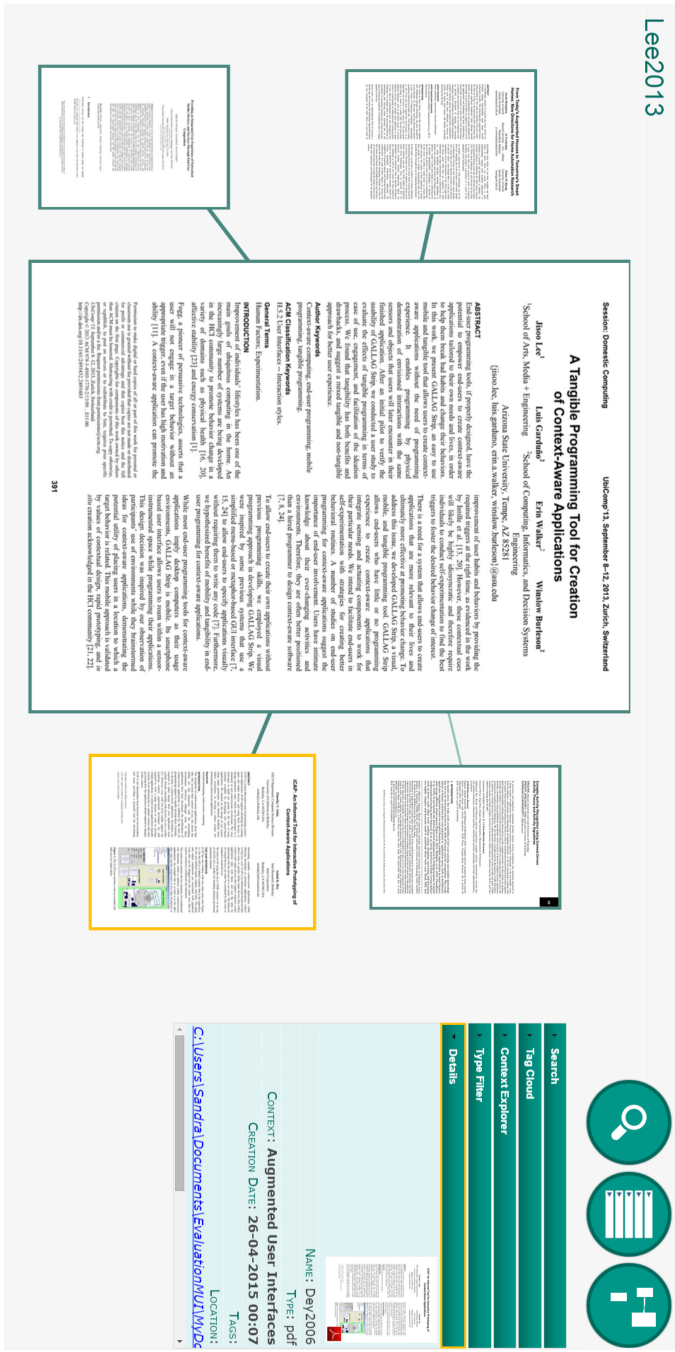



Figure 7.5.: Focus View

## 7.3 PIM-AC: THE AUGMENTED FILING CABINET

We have augmented a physical filing cabinet with a tangible user interface as our second proof-of-concept cross-media PIM user interface. The tangible user interface enables users to explore the content of the filing cabinet by means of contextual, temporal and spatial metadata provided by our DocTr framework. The filing cabinet consists of 26 augmented folders organised in three columns with ten, six and ten folders and a tangible control panel which is mounted in the centre column as shown in Figure 7.6. Furthermore, each folder has been augmented with a green, amber and blue LED. The LED interface serves as a medium to give the user feedback on which folders are related to each other (i.e. green for contextual, amber for temporal and blue for spatial relations) and to indicate the position of a searched physical document that is situated in one of the folders (i.e. the re-finding request is invoked by another user interface). In this case, all three LEDs will be highlighted.

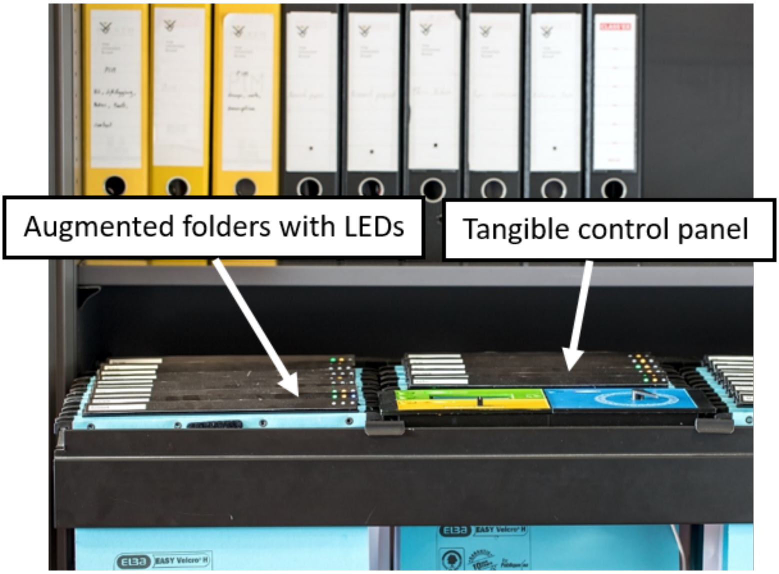



Figure 7.6.: Augmented filing cabinet

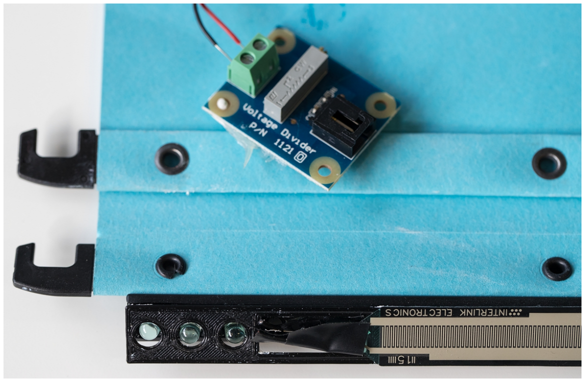



Figure 7.7.: Folders augmented with touch sensor and LEDs

At the start of the re-finding activity, users have to be able to select a physical folder. The filing cabinet foresees this interaction by allowing users to press the top of a folder. We augmented the top side of folders with an Interlink 24 inch 100N force sensing resistor (FSR) sensor as highlighted in Figure 7.7. The FSR sensors are connected to Phidgets I/O boards. When touching a folder, the augmented filing cabinet application is notified and sends the newly selected folder's ID to the UIM component on the server.

Once a user has selected a folder, the three components of the control panel shown in Figure 7.8 will be updated with the relevant information. The related contexts (i.e. contexts where the selected folder has been used in) are shown on the display of the green control panel's component. Users can browse the related contexts by using the buttons with the left and right arrows. When a context is selected, the green LEDs of the folders which are also used within the particular context will be highlighted. Furthermore, users can explore temporal relationships by using the physical slider in the yellow component. By placing the slider on a specific time interval, the amber LEDs of the related folders which have been used during the same hour, day, week or month will light up. Finally, the spatial re-finding cue is supported by the blue component. Users can move the arrow to a specific letter and as a consequence the blue LED of the folders starting with the particular letter will be highlighted. We used Phidgets sensors and display to enable the tangible interactions with the control panel. Note that interactions with the filing cabinet, such as changing the values of the components or selecting a physical folder, will invoke updates in the other subscribed cross-media PIM user interfaces as shown in Section 7.5.

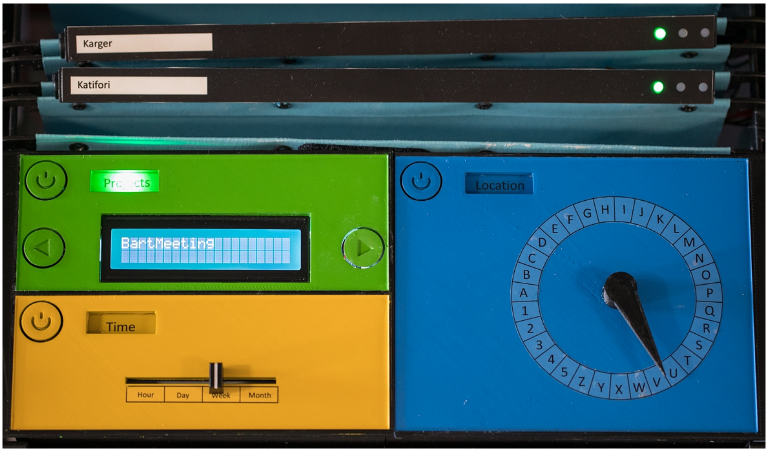



Figure 7.8.: Tangible control panel of the augmented filing cabinet containing three components for exploring contextual, temporal and spatial metadata of the documents

## 7.4 OTHER UBIQUITOUS USER INTERFACES

Besides the two large proof-of-concept applications, we have developed three smaller cross-media PIM user interfaces in a ubiquitous manner including two File Explorer extensions, augmented ring binders and an Android application. These user interfaces illustrate how existing tools and artefacts can be augmented with support for the three re-finding cues without major programming efforts.

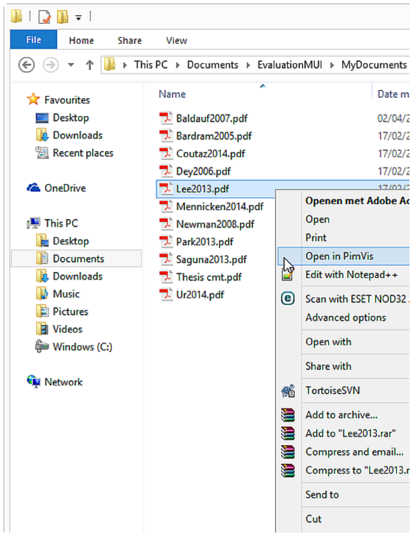
### *File Explorer Extensions*

The Windows File Explorer has been augmented in two ways with functionality to explore the metadata of a selected digital document. First, users can open the digital document in the Focus View by selecting the 'Show in PimVis' entry in the Windows File Explorer context menu highlighted in Figure 7.9a. This context menu extension has been implemented as a registry entry which starts a small Java program to notify the UIM framework about the requested interaction. Our second way to explore a selected digital document's metadata is provided by means of a File Explorer sidebar application shown in Figure 7.9b. The sidebar consists of three components similar to the ones of the augmented filing cabinet. When a user selects a digital document in the File Explorer, the data within the components will be updated with the appropriate metadata of the selected digital document. Each component consists of a combo box and a list of related digital and physical documents as well as physical folders. For example, the combo box in the green component includes all related contexts. When a user selects a context, the documents and physical folders used in this context will be shown in the list of the component. In a similar way, users can choose a time interval (same hour, day, week or month) in the amber component and a letter in the blue component.

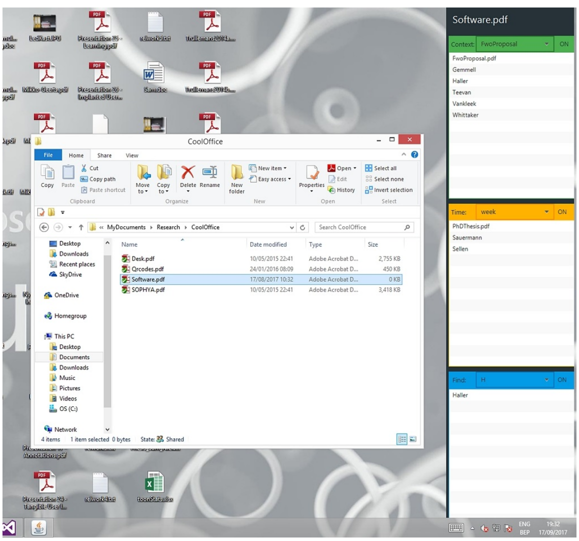
In order to show users the position of a digital document that is stored in the File Explorer, the File Explorer will be opened at the hierarchical level of the digital folder including the selected digital document. We choose for this feedback since it has been shown in related work that folder structures contain additional contextual information [58]. Note that any user interface can request to show the position of the digital document in the File Explorer.

### *Augmented Ring Binders*

While we have augmented ring binders with RFID tags in order to track their position (as discussed in the evaluation of DocTr in Section 5.4.1), we also augmented the ring binders with some re-finding functionality. In the back of the ring binder, we have mounted an LED which is controlled by a small Digispark module (i.e. an Ardiuno-based chip). The module is registered to the UIM framework and listens to notifications with regard to showing a physical document's position that is situated within the particular ring binder. Once the ring binder gets the notification, the module will highlight the LED for 20 seconds.




(a) Extension for PimVis




(b) Sidebar extension

Figure 7.9.: Two File Explorer extensions

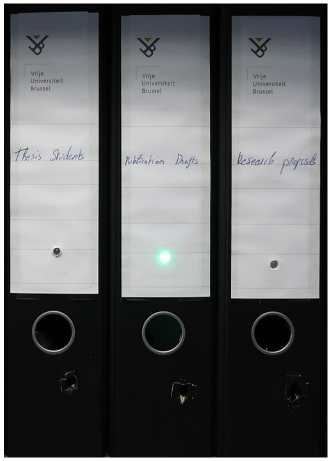


Figure 7.10.: Ring binders with LEDs

*Smartphone as a Prosthetic Memory Tool*

A final cross-media PIM user interface is our Android application. We designed the Android application by using a Swipe View layout where each view offers re-finding functionality for one of the three re-finding cues. The design of the application is similar as to the File Explorer sidebar where the Swipe View layout views have the same design as the three components of the sidebar. Moreover, each view has a spinner (i.e. Android's representation of a combo box) which contains the data for the possible queries (e.g. list of contexts in the context view) and a list of digital documents as well as physical folder which are related to the selected digital document or physical folder. The context, temporal and spatial views of the application are shown in Figure 7.11.

## 7.5 INTERACTIONS ACROSS CROSS-MEDIA PIM USER INTERFACES

In order to provide users with a seamless transition between the digital and physical information spaces, we foresee various interactions across the presented cross-media PIM user interfaces. In principle, the UIM framework allows all user interfaces to communicate their value changes of the components to each other as well as request other user

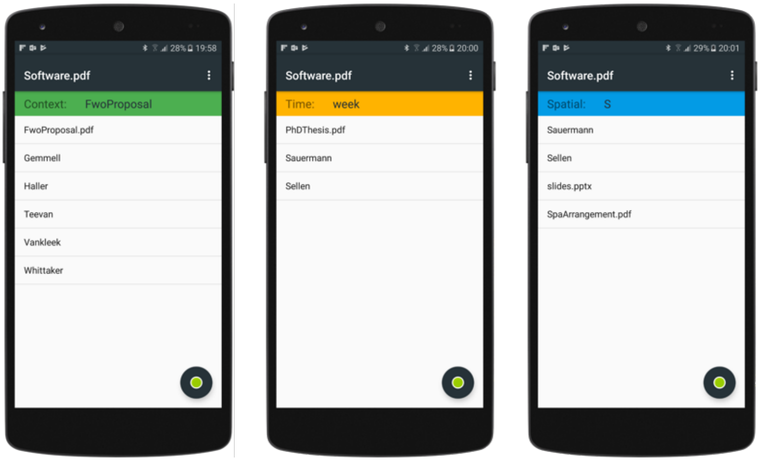



Figure 7.11.: Android application

interfaces to show the position of a specific digital or physical document. In the context of this dissertation, we limited the implementation of possible interactions to the ones that are necessary for using the user interfaces in the two user studies presented in Chapter 8. We provide the following user interaction possibilities across the presented user interfaces. For each user interface, we explain which interactions can take place between the user interfaces.

*PimVis*

**Interactions to other UIs:** By using the magnifying glass in the Focus View, the position of a digital document will be shown in the File Explorer and the position of a physical document by highlighting the ring binder including the document.

**Interactions from other UIs:** The Focus View will be opened with the selected digital document in the File Explorer or by placing a physical document on the monitored desk area (see implementation details in the evaluation of DocTr in Section 5.4.1).

*Augmented Filing Cabinet*

**Interactions to other UIs:** When the user selects a physical folder, the metadata of the particular folder will also be shown in the File Explorer

sidebar as well as in the Android application.
**Interactions from other UIs:** In case the user selects a physical folder in the File Explorer sidebar or Android application, the three LEDs of the particular physical folder will be highlighted as well as the appropriate LEDs of the related physical folders.

*File Explorer Extensions*

**Interactions to other UIs:** Selecting a digital document will show the related digital and physical documents in the sidebar and Android application as well as light up the appropriate LEDs of the related physical folders in the filing cabinet. A request to open the document in PimVis will show the Focus View of PimVis.
**Interactions from other UIs:** By using the magnifying glass in the PimVis Focus View as well as selecting a digital document in the Android application or File Explorer sidebar, the File Explorer will open the necessary digital folder and highlight the requested digital document.

*Augmented Ring Binders*

**Interactions to other UIs:** Users can place a physical document that is stored in a ring binder on the monitored desk area where PimVis will show the document in the Focus View.
**Interactions from other UIs:** By using the magnifying glass in the PimVis Focus View of a physical document, the LED of the ring binder containing the document will be lighted up.

*Android Application*

**Interactions to other UIs:** When the user selects a digital document, the document will be shown in the File Explorer. In the case of a physical document, the three LEDs of the physical folder containing the document will be lighted up.
**Interactions from other UIs:** Digital document and physical folder selections in the Android application, File Explorer sidebar and filing cabinet will update the Android application with documents related to the selected document or folder.

## 7.6 conclusion

In this chapter, we presented our UIM framework which is responsible to share search states across the cross-media PIM user interfaces and enables user interfaces to request other user interfaces to show the position or metadata of a particular digital or physical document. We further presented various proof-of-concept cross-media PIM user interfaces such as the PimVis application, an augmented physical filing cabinet and some smaller ubiquitous augmentations of commonly used tools and artefacts. Finally, we elaborated on how we provide a seamless transition between the presented cross-media PIM user interfaces.

# 8

# GAINING INSIGHTS INTO THE DESIGN SPACE

In this chapter, we explore the design space for the introduced cross-media PIM user interfaces by deploying two user studies. This will enable us to answer RQ3 of the presented dissertation. The first user study focusses on gaining insights in the overall user experience and opportunities for cross-media PIM applications. The study used PimVis combined with the augmented ring binders and the PimVis File Explorer extension. Our second user study includes a more in depth investigation of the use of cross-media PIM user interfaces with regard to their efficiency and support for the re-finding cues. The user study's setup included the augmented filing cabinet together with the Android application and the File Explorer sidebar. As part of the second user study, we also evaluate the main design principles for a cross-media PIM user interface namely the seamless transition between information spaces, the integration with the currently used organisational structures and the synergy with the organic memory. Finally, both user studies enabled us to define various design implications. Together with the three validated design principles, they inform the design space for our cross-media PIM user interface approach taken in this dissertation.

## 8.1 STUDY 1: UX AND THE SEAMLESS TRANSITION

We first define two research questions which will be answered by the presented user study. Next, we present the used study setup followed by the methodology. The results are structured according to the defined research questions.

### 8.1.1 *Research Questions*

The first user study will give us insights into the overall user experience and the seamless transitions between cross-media PIM user interfaces. We defined the following research questions:

**Research Question** (3.1)**.** *Does the use of cross-media PIM user interfaces leads to a positive user experience?* We choose to investigate the overall user experience in order to gain insights in the attractiveness, stimulation and subjective efficiency. Note that we did not deploy a usability study since this dissertation focusses on gaining insights into the design space through the development of advanced technology. We therefore do not state that the design of the presented user interfaces is the best option for final products with regard to usability.

**Research Question** (3.2)**.** *How do users perceive the seamless transition between cross-media PIM user interfaces?* In a first phase, we explored whether users make use of the opportunity to "jump" between the digital and physical space as well as what implications these cross-space interactions have on their re-finding strategy.

The results of the two research questions will enable us to gain first insights into a user's perception of the presented cross-media PIM user interface approach.

### 8.1.2 *Setup*

We have used the PimVis application together with the PimVis File Explorer extension, four augmented ring binders and the reacTIVision-based tracking setup which identifies paper documents on the monitored desk area as illustrated in Figure 8.1. When a digital document is shown in the PimVis Focus View and the user clicks the magnifying glass, the File Explorer will open the folder containing the digital document and highlight it. Users also can select a digital document in the File Explorer which will then be shown in the PimVis Focus View. In the case a physical document is shown in the PimVis Focus View and the magnifying glass is clicked, the LED of the ring binder containing the document will be lighted up. In order to open the PimVis Focus View of a physical document, users can place a document on the monitored desk area. This setup will allow us to explore how users perceive simple user interactions across the digital and physical information spaces.

Since we choose for a laboratory user study and in order to prevent bias from tracking errors, we manually entered the contextual, temporal and spatial metadata of the used digital and physical documents. Note that in a real setting the CMT and DocTr framework would automatically derive the necessary metadata of documents.

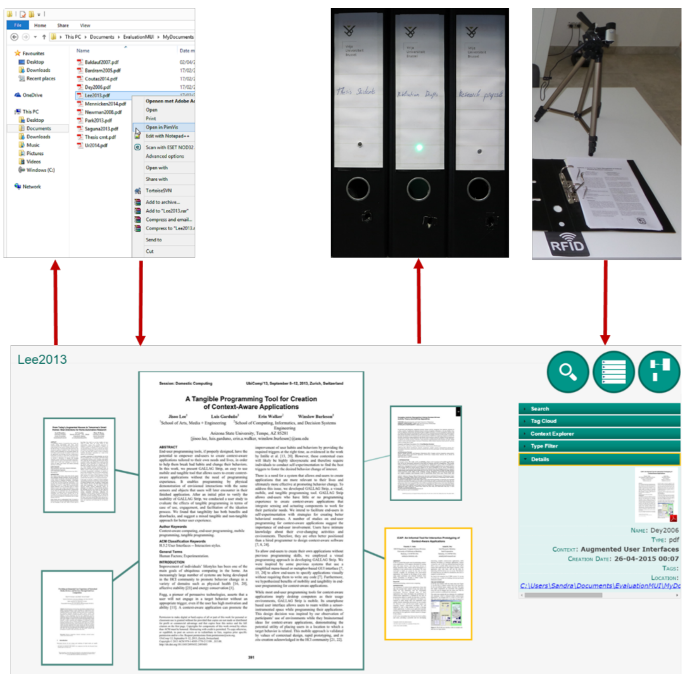



Figure 8.1.: Setup used in the first user study

### 8.1.3 *Methodology*

Before presenting the results, we will elaborate on the used procedure, measured variables and the selected group of participants. The evaluation op systems dealing with PIM data or using them as a mean to gain insights into a user's behaviour is not trivial. After all, the systems are designed with regard to information management of highly personalised data leading to the fact that for in-lab studies we would ideally have to adapt the information to each individual participant. From a methodological viewpoint, this approach would introduce significant bias since participants will not use the same overall system (e.g. some participants might have more/fewer documents or with various folder hierarchy structures leading to a non-controlled environment). Therefore, we followed the same approach as taken by Fitchett et.al. [37] and Boardman [14] and populated the setup with a co-worker's personal information. Participants were given enough time to get familiar with the documents in PimVis, the populated File Explorer and the physical documents in the four augmented ring binders.

#### *Procedure*

The participants performed six tasks which can be found in Appendix B. The individual tasks are small activities that one might perform while writing a research paper. Furthermore, the six tasks where split into two parts. In the first three tasks the user did not necessarily have to switch from PimVis to the connected file explorer or physical space. An example of a tasks from the first part is "*You want to read the paper 'Reality Editor'. This paper is related to the paper called 'ObjecTop' which you have used in your current context and is stored in the 'Papers' folder in the current directory.*". In this task, users could choose if they used the PimVis Context View or the File Explorer extension to navigate to the PimVis Focus View of the 'ObjecTop' paper. The three remaining tasks always required users to navigate between the user interfaces. An example for this second part of questions is "*Find the image with the 'LED in a ring binder' that you have taken while working on the Cool Office project. Which documents are related to this image? Open the image on your desktop computer.*". This design allowed us to investigate whether users naturally switch between the different cross-media PIM user interfaces. Finally, participants could only start with the study tasks when they finished the training session including similar tasks.

*Measured Variables*

During the tasks, participants were observed and after completion a semi-structured interview was conducted including questions related to why they applied observed interactions between the cross-media PIM user interfaces. In addition, participants filled in a questionnaire to evaluate the user experience. We have used the standardised user experience questionnaire of Laugwitz et al. [72] which evaluates the attractiveness, stimulation, perspicuity, dependability, novelty and efficiency. Each factor's value represents the mean of the answers of four to six questions with each question rated on a 7-point Likert scale between opposites such as 'annoying' and 'enjoyable'.

*Participants*

Our eight study participants were pre-doctoral university students with different backgrounds and with an age between 20 and 31. All participants had experience in the writing of research papers or Master's theses. We opted for this specific population due to the fact that these participants would be familiar with the given use case.

### 8.1.4 *Results*

We first report on the user experience results followed by the identified benefits and pitfalls for the design of cross-media PIM user interfaces.

**Research Question.** (3.1) *Does the use of cross-media PIM user interfaces leads to a positive user experience?*

Before the construction of the six user experience factors, a reliability analysis was performed. By removing on average one question for each factor, all factors have a Cronbach's alpha above 0.7. Nevertheless, we could not reach this analysis requirement for the novelty factor which therefore was not further used in the evaluation. The resulting mean values together with the standard deviation are shown in Figure 8.2. Note that since all mean values are above the neutral value of 4 on the

7-point Likert scale, we rescaled the resulting mean values to a scale from 0 to 3 with 0 representing the neutral value and 3 the highest value.

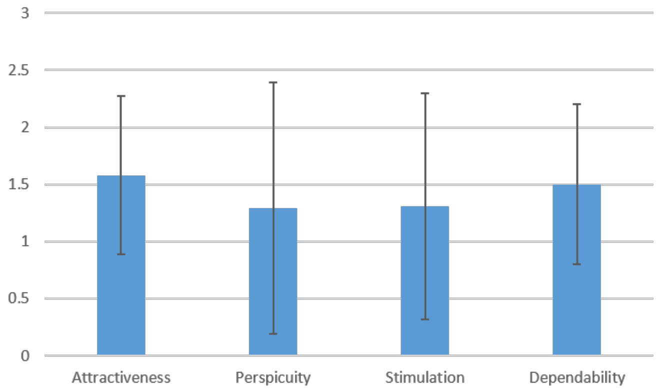



Figure 8.2.: The means for each analysed factor (0 is the neutral value) with error bars showing the standard deviation

The results show a positive evaluation of all five user experience factors. The participants found PimVis attractive to work with and they all agreed that it would make organisational and re-finding activities more efficient. Nevertheless, we can also identify that the standard deviation of the perspicuity factor is quite large. From our observations we could see that users were sometimes confused when doing some tasks which included interactions with the context menu in the Windows File Explorer. Moreover, users simply forgot that they could open the digital document in the PimVis Focus View through the context menu. Our interviews have shown that the main reason for this observation is the fact that the 'Show in PimVis' button is hidden in the context menu. Therefore, we have re-designed this interaction in a new version of the File Explorer extension that was used in the second user study. When users now select a digital document in the File Explorer, the other user interfaces will immediately be requested to update their state.

**Research Question.** (3.2) *How do users perceive the seamless transition between cross-media PIM user interfaces?*

While users well perceived the different interaction possibilities between the physical environment and PimVis, we could observe that the interactions between PimVis and the File Explorer caused some confusion due to traditional ways of working with digital documents. For example, in order to open the digital document in the File Explorer from the PimVis Focus View, users sometimes tried to click the given document's path in the Focus View detail panel. Since this interaction was not working, some users copied the document's path to the File Explorer instead of using the magnifying glass button. However, when participants were asked if they would also prefer to click the physical document's label instead of the magnifying glass in order to show the physical position of the document, they all gave a negative response. They argued that the navigation to the detail panel to find the document's label would cost too much time compared to the direct access to the magnifying glass button. In contrast, they would do the navigation effort for digital documents since that is how they are used to interact with them as illustrated by one of our participants: *"I actually totally forgot to use the magnifying glass button. Stupid. I just thought how I could get to the URL of the document. That is how you open a document, right?"*. We must take into account the established ways of interacting with digital documents in the design of cross-media PIM user interfaces. This might lead to the fact that different ways for doing the same task must be provided depending on the design for digital or physical documents.

A second observation is that the participants commonly started to solve the tasks in the user interface (i.e. PimVis visualisation or Windows File Explorer) they were busy with from the previous task, even if that was often not the fastest way to solve a task. For example, if the previous task finished with some interaction using the Windows File Explorer, they would first search for a document in the Windows File Explorer when starting the next task. Only after spending on average 25 seconds without a result, participants decided to switch to the PimVis visualisation in order to explore the content via contexts. The same phenomena was observed the other way around. For some tasks where it would have been possible to, for example, just navigate to the picture folder in the

File Explorer, participants first navigated through the PimVis context hierarchies.

## 8.2 STUDY 2: UNDERSTANDING THE USER'S INTERACTIONS

The second user study focussed on gaining in depth insights into how the user interfaces are used, their efficiency and to which degree support the three re-finding cues. It further provides a validation for the proposed three main design principles for cross-media PIM user interfaces.

### 8.2.1 *Research Questions*

We defined four research questions in order to investigate the previously mentioned aspects of the proposed cross-media PIM user interfaces.

**Research Question** (3.3)**.** *Will users use the same re-finding strategies within and across information spaces?* The first research question will focus on how users interact with the cross-media PIM user interfaces. Are there any differences in the use of the components which support the re-finding cues? Do they use cross-media interactions?

**Research Question** (3.4)**.** *Does the efficiency or cognitive effort influences the use of the components supporting the re-finding cues?* Since the three components supporting the three re-finding cues may not be equally efficient or may require a different level of cognitive effort, we might state that users will prefer the most efficient component as a support during the re-finding activity. This would be in line with the results of the study of Kalnikatité and Whittaker [60] where it has been shown that the choice of a prosthetic memory is influenced by its efficiency.

**Research Question** (3.5)**.** *Are the re-finding cues used in a complementary way?* In the third research question, we will investigate whether users switch between re-finding cues and why or why not. For example, it might be possible that when the use of the contextual re-finding cue fails or is cognitively too loaded that users switch to another re-finding cue.

**Research Question** (3.6)**.** *Are the three design principles for cross-media PIM user interfaces significantly beneficial to the design?* We will validate the three design principles namely the seamless transition between information spaces, providing support for the use of the re-finding cues and the integration within the user's currently used tools or storage artefacts. Moreover, we will investigate to what extent the formulated design principles contribute to the usefulness and user satisfaction of cross-media PIM user interfaces.

### 8.2.2 *Setup*

In this second user study, we used the augmented filing cabinet combined with the File Explorer sidebar and Android application as illustrated in Figure 8.3. All three cross-media PIM user interfaces followed a similar design where support for the three re-finding cues is provided by the three components (i.e. green for contextual, amber for temporal and blue for spatial metadata) as described in Section 7.3. Furthermore, when a user selects a digital document in the File Explorer or Android application or a physical folder in the augmented filing cabinet, all user interfaces will be updated with the information of related documents or folders. The augmented filing cabinet has been populated with 26 folders containing research papers of researchers active in the PIM field. Each folder was labelled with a researcher's last name. Similar to the first user study, we also made an artificial digital folder structure.

### 8.2.3 *Methodology*

Before presenting our results, we elaborate on the used research design, procedure and how the variables have been measured.

#### *Research Design*

The user study used an embedded case study research design. In order to gain insights in the four research questions, we defined four individual cases as shown in Table 8.1. Each case focusses on the use of prosthetic memory for a particular re-finding cue (i.e. contextual, temporal or spatial) whereas the last case investigates the used re-finding strategy when support is given for all re-finding cues. Furthermore, within each case we observed the use of cross-media PIM user interfaces for re-finding activities which are limited to the digital information space and physical information space. Additionally, we also include re-finding

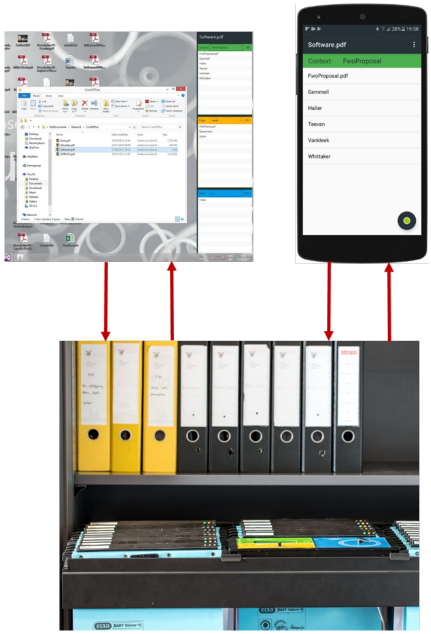



Figure 8.3.: Setup used in the second user study

activities where users had to cross the boundary of each information space and activities where they could choose to work in one information space or to use cross-media interactions.

*Procedure*

We defined small re-finding tasks for each of the possible spaces in which the re-finding activities took place and this for every case. The 16 tasks can be found in Appendix BAn example of a re-find task in the context case where the user could only use the physical space is *"Show all physical folders which are related to the `CoolOfficeProject`. You remember that you accessed the folder `Jervis` during the project."* Further, an example of the temporal case where users must use cross-media interactions is *"Open the digital document `CHI2018.pdf`. You remember that you have used the physical folder `Dix` within the same day."*. In total each case included six tasks where one task was made for the digital only and physical only

| Cases | Space of the re-finding activity |
|---|---|
| Contextual | only digital space |
| Temporal | only physical space |
| Spatial | must use cross-media |
| All re-finding cues | may use cross-media |

Table 8.1.: Overview of the four cases and the spaces in which the re-finding activities took place.

space re-finding activities. We defined two tasks for re-finding activities where users must and may use cross-media interactions since in these situations users can go from digital to physical space but also the inverse. Finally, we counterbalanced the cases and information spaces in which the re-finding activity had to take place.

In each case, the particular component supporting the specific re-finding cue in the three presented cross-media PIM user interfaces was enabled while the other components where disabled. Additionally, depending on the space of the re-finding activity, users where told which space they had to use. For example, if the user had to solve a re-find task of the context case in only in the physical space, they were instructed to use the augmented filing cabinet where only the context component of the control panel was enabled and the other components disabled.

Before solving the tasks of the study, users first had to finish the training phase consisting of 16 similar tasks. During the training, they could ask for clarification on all aspects of the setup. The users could start the tasks when they were familiar with the system as well as if they did not have questions left. The average time that users spent on solving all 16 tasks during the study was 26 minutes. After the tasks, users where asked to complete a questionnaire and open interviews where completed around observed interactions they did during the tasks.

*Quantitative and Qualitative Variables*

Since our user study focussed on gaining insights of the user's interactions with the proposed cross-media PIM user interfaces, we used quantitative as well as qualitative variables. The quantitative variables focus on the efficiency of the given user interface and how much cognitive effort the user experienced when using them. The variables were measured as follows:

- Efficiency: The time that users took to solve the task. The time that users spent to read the task was not taken into account.
- Perceived Cognitive Effort: After each task the user had to indicate how much cognitive effort it took them to solve the task. The factor is measured on a 5-point Likert scale.

Besides the quantitative measurements, we also defined factors which were the main point of focus during the observations such as the use of a cross-media PIM user interface, how cross-media interactions were done and the mental model of the user during the search. Furthermore, a questionnaire enabled us to gain insights in the usefulness and satisfaction of cross-media PIM user interfaces. The validation of the three design principles was also measured by the questionnaire. For each design principle, we formulated multiple statements which users had to grade on a 7-point Likert scale form strongly agree to strongly disagree. Users filled in the questionnaire after the completion of all tasks.

*Participants*

We recruited 15 participants between 23 and 54 years old. In their daily activities, all participants use paper documents complementary to digital documents. The professions ranged from academics to secretaries and managers working in industry. Participants were not given any compensation and could leave the study at any moment.

## 8.3 RESULTS

The results are organised according to the previously defined research questions. We used the Chi-Squared Goodness-of-Fit to see a significant difference in the distribution of a category and the Wilcoxon signed-rank test was used to compare differences between variables since a normal distribution could not be guaranteed. When a significant difference is mentioned between factors, it is always significant at the level of $p < 0.05$.

**Research Question.** (3.3) *Will they use the same re-finding strategies within and across information spaces?*

Our results show an equally distributed use of the components when users where given the option to choose which component they use to solve a task in digital space only or when navigation between spaces was needed. In contrast, when solving tasks in only physical space users mainly used the context component (9/15) ($\chi^2(2) = 8.4, p = 0.015$). Additionally, we see that users did not have a subjective preference concerning the used component when doing tasks in only digital or physical space. They did have a preference for the context component when navigation would be required between information spaces ($\chi^2(2) = 6.4, p = 0.041$). Our observations and open interviews indicate that users subjectively did not have a preference for the context component in the filing cabinet, although they used it significantly more during the tasks. This can be caused by the fact that they lacked a quick overview of the related contexts since the display did not show a list of available contexts. An alternative design, for example by showing the related contexts in a list form, could increase the preference to use the context component in the physical space.

During tasks where users had to navigate between information spaces, we observed that only 2 out of 15 users used the Android application to explore related digital documents for a selected physical folder in the filing cabinet. Moreover, users could easily construct a mental model about where which information would be available. For example, a user commented *"I did not use the phone since I can just see the same in the sidebar next to the File Explorer and continue my search from there. I would only use the phone if I am not sure I selected the good folder in the filing cabinet."* Similarly to other participants, they would use the Android application mainly in cases where they would not be confident that the selected folder would help them in the digital search and in cases where users would do an exploratory search activity to gain more insights in their organisational landscape.

Besides the observations on the use of the Android application, we could also witness the use of the physical filing cabinet when users searched for digital documents even though they could also just stay in the digital space. This behaviour has been significantly applied when using the temporal ($\chi^2(2) = 8.06, p = 0.005$) and context component

($\chi^2(2) = 5.4, p = 0.020$). Users started their search by selecting a physical folder and continued the search by using the File Explorer sidebar application to actually retrieve the digital document. Note that the assignments included both, the path to a related digital document and the label of a related physical folder. Commonly, users mentioned the fact that just selecting the physical folder was less "steps" away from their goal than first digitally navigating to the given related digital document in the folder hierarchy. Additionally, users pointed out that in the end the result would be the same which shows that users had constructed a mental model of the information available in the augmented tools.

**Research Question.** (3.4) *Does the efficiency or cognitive effort influence the use of the components supporting the re-finding cues?*

Our results show a significant efficiency difference between all components for each information space as well as for cross-media interactions where users have to navigate between information spaces. The values of the Wilcoxon signed-rank tests and their significance are provided in Table 8.2. For each information space and cross-media interaction, the spatial component was more efficient than the temporal and context component as illustrated in Figure 8.4. Additionally, we can observe that the context component is the most inefficient compared to the temporal and spatial component. While the context component is the most inefficient component to use, users still used this component significantly more than the other components for tasks in the physical information space as shown previously. Participants mentioned the issue that in the filing cabinet the context was totally lost whereas in digital space they could reason over the file path of a digital document. This finding is in line with previous PIM research where it has been shown that the digital folder hierarchy has been used to preserve contextual information about documents and that physical filing cabinets are often augmented with digital indexes and notes [58, 101]. Furthermore, we observe that the efficiency is significantly different for all components but that there is no difference in the degree of use of the components in digital space and cross-media interactions. Therefore, we can conclude that efficiency does not play a significant role in the decision which component will be used.

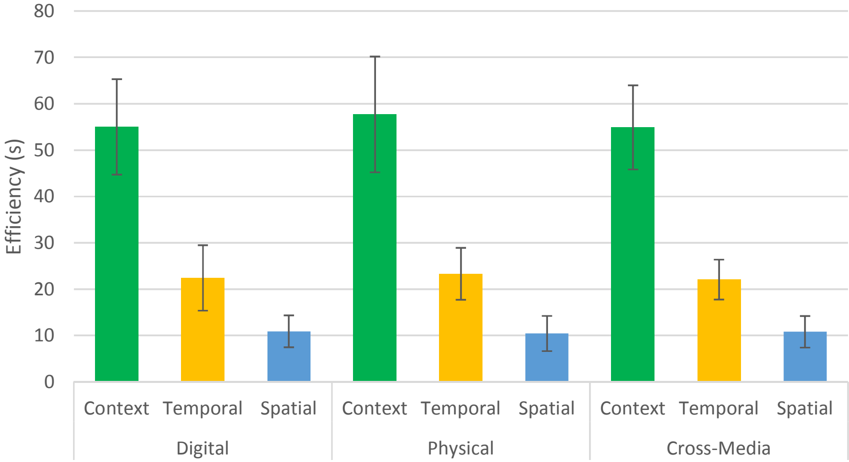



Figure 8.4.: The efficiency of each component in each space with the error bars representing the standard deviation

| | Digital | Physical | Cross-Media |
|---|---|---|---|
| Context-Temporal | $z = -3.4$<br>$p = 0.001$ | $z = -3.4$<br>$p = 0.001$ | $z = -3.4$<br>$p = 0.001$ |
| Context-Spatial | $z = -3.4$<br>$p = 0.001$ | $z = -3.4$<br>$p = 0.001$ | $z = -3.4$<br>$p = 0.001$ |
| Temporal-Spatial | $z = -3.1$<br>$p = 0.001$ | $z = -3.1$<br>$p = 0.001$ | $z = -3.$<br>$p = 0.001$ |

Table 8.2.: Comparison of efficiency across components in each space with the corresponding Wilcoxon Signed Rank value ($z$) and significance ($p$)

Similar to the efficiency results, we could observe significant cognitive effort differences between the use of the three components for each information space and cross-media interactions as illustrated in Figure 8.5 and detailed in Table 8.3. The use of the context component requires significantly more cognitive effort than the use of the temporal and spatial component. Additionally, the temporal component imposes more cognitive effort than the spatial component. Finally, we can observe that the efficiency and cognitive effort do not significantly influence the usage of a specific component. Our interviews showed that this behaviour is not surprising since users did often not take into account the efficiency and cognitive effort in their decision process when choosing a component. They mentioned factors such as the minimum amount of clicks or folder selections, the possibility to get a fast overview of related documents and the component which could follow their current reasoning which influenced their decision on the use of a specific component.

| | Digital | Physical | Cross-Media |
|---|---|---|---|
| Context-Temporal | $z = -1.9$ $p = 0.52$ | $z = -2.9$ $p = 0.003$ | $z = -2.6$ $p = 0.007$ |
| Context-Spatial | $z = -3.2$ $p = 0.001$ | $z = -3.4$ $p = 0.001$ | $z = -3.3$ $p = 0.001$ |
| Temporal-Spatial | $z = -3.2$ $p = 0.001$ | $z = -3.1$ $p = 0.002$ | $z = -2.7$ $p = 0.006$ |

Table 8.3.: Comparison of cognitive effort across components in each space; Wilcoxon signed-rank value ($z$) and significance ($p$)

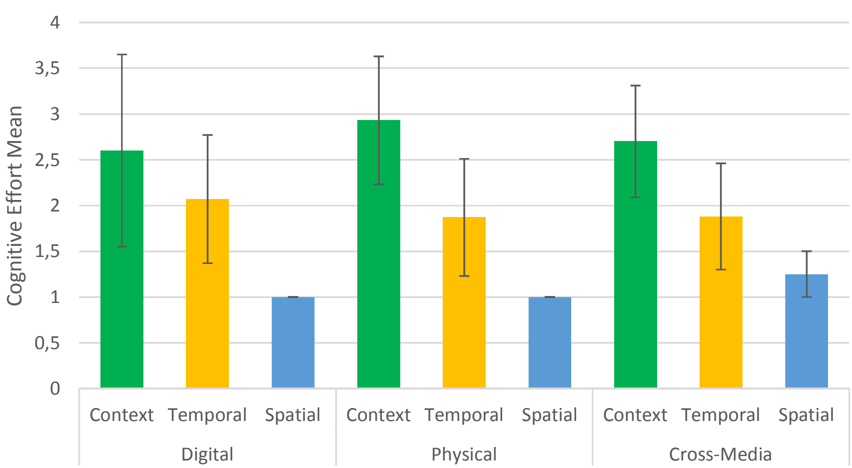



Figure 8.5.: The means of cognitive effort for each component in each space with the error bars representing the standard deviation

**Research Question.** (3.5) *Are the re-finding cues used in a complementary way?*

We could not observe a complementary use of the components within the digital or physical information space or during the cross-media interactions. Although the use of the context component required more time and cognitive effort, users did not switch to another components. Furthermore, users mentioned that in their daily life they would also not often switch between components. In contrast, in moments where they wanted to explore the relationships between digital and/or physical documents the components would be used in a complementary way (10/15).

**Research Question.** (3.6) *Are the three design principles for cross-media PIM user interfaces significantly beneficial to the design?*

The three design principles were formatively evaluated by asking users to grade statements. The evaluated factors for each design principle with their mean scores are shown in Figure 8.6. Note that the factors have been measured on a 7-point Likert scale ranging from strongly agree to strongly disagree). Note that since all mean values are above the neutral value of 4 on the 7-point Likert scale, we rescaled the resulting mean values to a scale from 0 to 3 with 0 representing the neutral value and 3 the highest value.

The results of the evaluation of the design principles stating that cross-media PIM user interfaces have to be integrated in the user's currently used tools shows an overall positive score. Although users find both, the File Explorer and filing cabinet augmentations equally useful, our results of the Wilcoxon signed-rank test show a significant difference concerning the satisfaction factor. Users are more satisfied about the augmented filing cabinet than the File Explorer extension ($z = -2.6, p = 0.008$). These results are in line with the fact that most users also used the filing cabinet as a starting point to search for digital content.

Similarly to the first design principle, we can observe a positive evaluation for the design principle where cross-media PIM user interfaces have to provide support for a user's re-finding cues. Users see the proposed user interfaces as an extension of their memory and they confirm that the user interfaces provide enough support for the used re-finding cues as shown in Figure 8.6. These subjective user findings are in line with

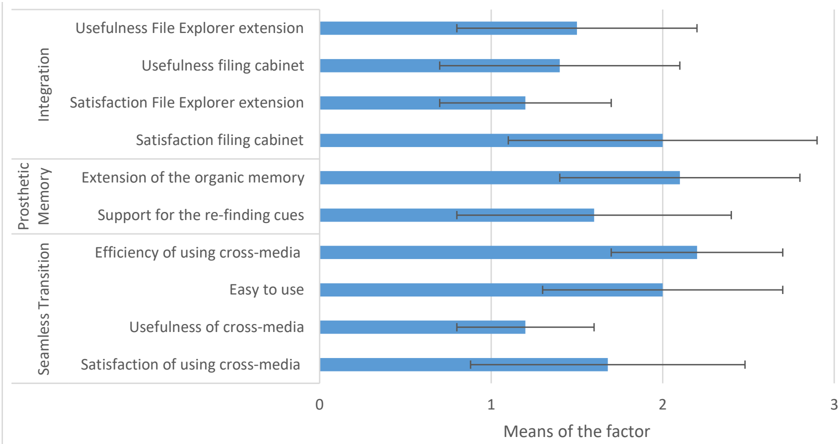



Figure 8.6.: Satisfaction and usefulness of the three design principles with the error bars representing the standard deviation

the results discussed in RQ3.1 where we have shown that users equally used the provided components which support the re-finding cues.

The seamless transition between the digital and physical information space has been evaluated by asking users to grade four factors. In general, our results show again a positive evaluation as shown in Figure 8.6. Users found that using cross-media interactions made their search more efficient and that the seamless navigation between information spaces is easy to use and useful. Finally, they are positively satisfied about the level of the foreseen seamless transition between information spaces. We could observe similar results in our first user study where users made extensive use of the opportunity to navigate between the cross-media PIM user interfaces. In contrast to the results of the first user study, participants did not mention issues related to the use of the File Explorer extension used in this user study. This can be motivated by the fact that we re-designed the File Explorer extension by replacing the hidden context menu interaction with the document selection interaction as described in Section 7.5.

## 8.4 GUIDING THE DESIGN OF CROSS-MEDIA PIM USER INTERFACES

The results of our user studies show that the design of cross-media PIM user interfaces is a promising approach to decrease the fragmentation problem across information spaces. Additionally, the results enabled us to describe a set of design implications for the future design of our introduced cross-media PIM user interfaces.

**Design Implication 1.** *The Starting Point is Mostly the Current Application* During the observations which took place in both user studies, we could see that users often started their search in the tool or information space where they finished a previous assignment, although it was often not the fastest way to solve a task. In some observed use cases, participants only realised after on average 25 seconds that their re-finding strategy was failing where they switched to another user interface. However, commonly the initial re-finding strategy which failed took only a few seconds and was mainly observed when the File Explorer was last used. Participants mentioned that it was a habitual activity to re-find digital documents in the File Explorer. We also observed that the duration of this initial failed re-finding strategy was less with the second File Explorer extension which had a sidebar displaying related documents and folders. The closely integrated sidebar made users aware of the extra functionality they could use. While we observed this behaviour commonly with File Explorer interactions, it was only sporadically the case for the other user interfaces.

**Design Implication 2.** *Support Search for Digital Media in Physical Space* Even when users are aware that they can re-find a digital document by only applying search interactions in digital space, they commonly used the filing cabinet to start the orienteering process. A reason for this behaviour is the fact that selecting a physical folder required fewer navigation steps than traversing through the digital folder hierarchy. Additionally, users commented on the affordances of the physical space such as the spatial awareness (i.e. visual overview) it provides when exploring the personal information space and that physical document manipulations were subjectively easier than clicking interactions in digital space. Future cross-media PIM user interface design might, for example, enable re-find interactions for digital documents by allowing users to point to a physical document or artefacts containing physical documents.

Finally, augmented reality can be used to display digital documents which are related to physical organisational structures and where tangible interactions are foreseen to support queries on the metadata of digital and physical documents during the re-finding process.

**Design Implication 3.** *Different Spaces, Different Re-finding Cues*
Our results show a significant difference in the used re-finding cues across information spaces. While in the digital information space users equally applied all three re-finding cues, in the physical information space they used the contextual cue more often than the other re-finding cues. Thereby, when designing cross-media PIM user interfaces, we have to take into account for which space they are designed. In both information spaces support has to be foreseen for all three re-finding cues since there is no consistent usage behaviour of the re-finding cues. However, cross-media PIM user interfaces which augment the physical information space have to provide advanced support for the contextual cue. While users currently squeeze contextual information of documents in the digital folder hierarchy, they cannot do this in the same extensive way in physical filing cabinets. This might be a reason why in the physical space users rely more on the context component of the foreseen prosthetic memory than in the digital information space.

**Design Implication 4.** *Differences in Hot and Cold Documents*
Most participants were very pleased with the small ubiquitous user interfaces such as the Windows File Explorer extensions, the ring binder augmentations with LEDs and the augmented folders. Furthermore, they came up with interesting use cases how they might use these types of ubiquitous user interfaces in their own workplaces. Often users indicated that it would be nice to have the sidebar Windows File Explorer extension for so-called hot documents. These are documents which are used in short-term tasks. In contrast, for archived documents a more supportive application such as PimVis is desired. For physical augmentations this might mean that pointing to a specific ring binder is not sufficient but also the exact location within the ring binder should be indicated. Designers should take into account for which kind of documents they design cross-media PIM user interfaces.

**Design Implication 5.** *Ubiquitous User Interface Design*
We further aim for an integration of prosthetic memories in tools which users use for organising digital documents as well as in the form of an augmentation of their used artefacts for organising physical documents. Cross-media PIM user interface design can best be provided in a uniform ubiquitous manner. We have seen that users easily grasp the notion that results of certain selections in a particular component are available in the other augmentations. Moreover, they are aware that metadata of digital and physical documents is available everywhere regardless of the information space. Additionally, users extensively used this awareness during tasks by seldom using the Android application on the smartphone as an intermediate bridge between filing cabinet and File Explorer interactions. Furthermore, users often indicated whether it was possible to augment their own tools and artefacts. The most common request was to provide augmentations for piles on their desk and the Evernote application. This shows that users value the ubiquitous integration of these user interfaces in their own organisational landscape.

**Design Implication 6.** *End-User Control of User Interfaces*
During our user studies, users eagerly brainstormed about how the cross-media PIM user interfaces could be integrated into their own organisational landscape. A common aspect was the ability to customise what actions the user interface should take when requesting to show the location of a document or physical folder. For example, users mentioned that depending on the task they are doing, a digital document should open immediately after the selection in a user interface instead of showing its location in the File Explorer. Similarly for the physical information space, ring binders can be augmented with displays which show related digital documents on the ring binder itself. Besides the customisation of actions taken after a re-finding activity, users value the ability to decide which artefacts and tools should be augmented. Moreover, not every organisational structure or tool has to be augmented with a cross-media PIM user interface. Users mentioned the disadvantages of the cases when, for example, every pile would be augmented with re-finding support. Since piles are often used to store hot information, the organic memory will still be able to provide enough triggers for the re-finding cues. However, users did agree in the case of piles that a solution such as providing cross-media PIM user interfaces on demand would give them

advantages in situations where the organic memory fails or when they do exploratory activities within the personal information space instead of directed re-finding activities. We aim to provide end-user control of the cross-media PIM user interfaces at the interaction level as well as for the integration of the user interfaces in their office environments.

## 8.5 CONCLUSION

In this chapter, we gained insights into the design space of our proposed cross-media PIM user interfaces. Moreover, our first user study investigated the overall user experience and the seamless transitions between digital and physical information spaces. The second user study focussed on the use and efficiency of cross-media PIM user interfaces as well as the support for the re-finding cues. Additionally, we have validated the three main design principles namely the seamless transition between information spaces, providing support for the re-finding cues and the integration with the user's current organisational landscape. The results of both user studies also enabled us to define six generic design implications. These design implications together with the three main design principles form the foundations for the design of our introduced cross-media PIM user interfaces.

# Part IV

# SUMMARY

# 9

# CONCLUSIONS AND FUTURE WORK

On a daily basis, we receive, store and reuse a significant amount of personal information. This might happen for personal as well as professional reasons. Although we often place significant effort in organising received or created documents, we frequently face problems in re-finding the right information for the task at hand. Issues related to organising and re-finding personal information are addressed by the multi-disciplinary research field of Personal Information Management (PIM). We can observe two main causes for the ineffectiveness of re-finding digital documents. First, users organise documents in a way that is not supporting the used re-finding mechanisms of the organic memory with digital documents widely spread over various tools, devices and cloud platforms. Secondly, we still often use digital and physical documents in a simultaneous way leading to the fact that the needed information becomes even fragmented across the digital and physical information space. While significant research has been undertaken on investigating the user's behaviour and the design of helpful PIM tools, existing approaches mainly focussed on either the digital or physical information space, often neglecting the complementary use of digital and physical documents.

In this dissertation, we took a cross-media approach to PIM application design by introducing the vision of *Cross-Media PIM User Interfaces*. Based on the results of multiple user studies, we defined the following three main design principles for our new type of user interfaces:

- They have to foresee a seamless transition across the digital and physical information space;
- They have to be integrated in the user's currently used tools such as the File Explorer and physical storage artefacts;

- They have to support the re-finding mechanism of the organic memory;

We first discuss our contributions against related work and also indicate some limitations of the presented work. This is followed by some overall conclusion and an outline of future work.

## 9.1 DISCUSSION AND LIMITATIONS

In order to investigate our vision of cross-media PIM user interfaces, we formulated three main research phases. We first gained insights into the users' cross-media PIM behaviour (RQ1). Next, we developed the necessary software to enable the design of the cross-media PIM user interfaces (RQ2) which was followed by an exploration of the design space for the introduced cross-media PIM user interfaces (RQ3). Our discussion is structured with regard to each main research question where the results are discussed by taking into consideration the existing body of related work.

### 9.1.1 *Gaining Insights Into Cross-Media PIM Behaviour*

We gained in depth insights into users' cross-media PIM behaviour by using the results of our previous work on how users organise and re-find documents across the digital and physical information space as well as by deploying two additional user studies. In the first user study, we investigated the opportunities to achieve a synergy between the design of prosthetic memory and a user's organic memory. Finally, we defined user-centric as well as technical requirements based on the findings of a second exploratory user study. The gained insights allowed us to define three main design principles for cross-media PIM user interfaces.

#### *Organising and Re-finding Documents*

Significant research has been investigating on how users organise physical documents as well as why the re-finding of documents is often a burden [79, 119, 92]. We can also observe that the organisation of digital documents is very similar to physical documents (i.e. use of hierarchical structures) where users face similar re-finding issues [7, 11, 58]. The fragmentation of digital documents over different tools, devices and cloud platforms introduces an additional cognitive effort during the re-finding activity [14, 110]. Although the research context of some studies included both information spaces, often their main goal was to learn from paper documents to form the design of digital interactions [15, 24]. Our previous work extended this body of state-of-the-art in descriptive PIM research by providing some fundamental findings through the definition of a new organisational strategy called mixing, which is supplementary to the filing and piling strategies defined by Malone [79]. The results further show that there is no correlation or dependency between the applied organisational strategies. Therefore, cross-media PIM user interfaces can be designed individually for each organisational structure. In addition, we identified which re-finding cues (i.e. contextual, temporal or spatial) are used within the digital and physical space for a particular organisational strategy. We have shown that the contextual cue plays a major role during re-finding of digital as well as physical documents. While users do significant efforts to keep the contextual metadata of digital and physical documents organised in files by, for example, using annotations and extensive folder labels, piles preserve this metadata as described in related work [92, 6, 19]. Finally, we could notice the use of the temporal and spatial cues for some organisational strategies and the fact that the spatial cue is more used than the temporal cue in the physical space. This is mainly implied by the fact that the physical space, by nature, offers more spatial reference points than the digital space. Note that this research was part of previous work and is briefly included in this dissertation for clarity purposes.

*The Synergy Between Prosthetic and Organic Memory*

Although the design of prosthetic memory is well-established in applications for meeting or learning purposes [117, 126, 106], less is known on how synergy can be achieved between prosthetic and organic memory in the context of PIM. The controlled laboratory study of Kalnikaité and Whittaker [60] takes a first step towards understanding the design of prosthetic memory for PIM where the use of notes, a dictaphone and ChittyChatty [60] (i.e. a tool where notes and recorded audio are temporally co-indexed) as prosthetic memory are compared. Similar to our second user study, participants were given three short stories and at three retention intervals (1 day, 7 days and 30 days) they were asked to answer questions about the particular stories with the help of a prosthetic memory. While the results of Kalnikaité and Whittaker show that the accuracy and efficiency plays an important role in the choice of a prosthetic memory, our results indicate that the main factor influencing the choice is the availability of support for the contextual re-finding cue regardless of its efficiency. However, we have seen that the contextual cue is less triggered after 30 days leading to the case that users start to make a cost/benefit analysis of using another prosthetic memory supporting a different re-finding cue. The accuracy and efficiency of the alternative prosthetic memories are taken into account during the cost/benefit analysis. In the design of cross-media PIM user interfaces, we should therefore also provide support for the temporal and spatial cue next to the contextual cue. Finally, our results show that the use of PM does not increase at longer retention intervals which is in line with the findings of Kalnikaité and Whittaker as well as the work of Lyons [78]. We acknowledge some limitations of our work. The limited number of 14 participants might have influenced the study outcome. However, we did not do any empirical statements rather explored how prosthetic memory stands in relation to the used re-finding cues.

*User-centric Requirements*

In a last research phase, we deployed an exploratory user study which provided us insights in factors which are subjectively important to users with regard to tracking and re-finding functionality of digital and physical documents in the augmented office. We could identify that providing re-finding support at the level of organisational structures (e.g. ring binders or folders) in addition to the documents themselves will give them addition triggers for the use of the re-finding cues. Secondly, we should monitor the flow of a document in order that they can reflect on previous positions of a document. Finally, users would like to add custom annotations and prefer to have supporting PIM tools which are integrated in the third-party applications they are using today. These are the main user-centric requirements to take into account in the design of an overall PIM solution.

*Towards the Three Main Design Principles*

While existing cross-media PIM applications such as the augmented filing cabinet of Lawrie and Rus [73], the Human-Centered Workspace [32] and SOPHYA [51] focus on the technical aspects of tracking physical documents, the supported re-finding functionality is limited and not based on user-centric requirements. In contrast, we combined the results from the previously mentioned three user studies to define the three main design principles for our cross-media PIM user interfaces. First, the user interfaces must foresee a seamless transition within and between the digital and physical information spaces and they must provide users a unified view over their personal information. Secondly, the three re-finding cues used by the organic memory should be supported in the design. Finally, user interfaces must be integrated in a user's constructed digital and physical environment by, for example, extending existing applications or augmenting used storage artefacts. We defined these main design principles in a generic way since it will depend on the use case and environmental setup how the particular implementation of these design principles will be manifested in the design of a particular cross-media PIM user interface. However, we showed throughout this dissertation that the three generic design principles form the initial basis of the design of any cross-media PIM user interface.

### 9.1.2 *Enabling the Design of Cross-Media PIM User Interfaces*

In order to enable the design of cross-media PIM user interfaces, we developed multiple software frameworks as illustrated in Figure 9.1. The DocTr framework is responsible for tracking temporal and spatial metadata of digital and physical documents as well as the corresponding organisational structures. The storage of this metadata is made possible by our Object-Concept-Context (OC2) PIM framework. On the other hand, the Context Modelling Toolkit has been designed to determine which documents or organisational structures have been used during a certain task. This contextual knowledge is given to the DocTr framework which makes the appropriate associations in the OC2 framework. Finally, we developed the User Interface Management (UIM) framework in order to enable cross-media PIM user interfaces to enable a seamless transition between user interfaces spread across the digital and physical space.

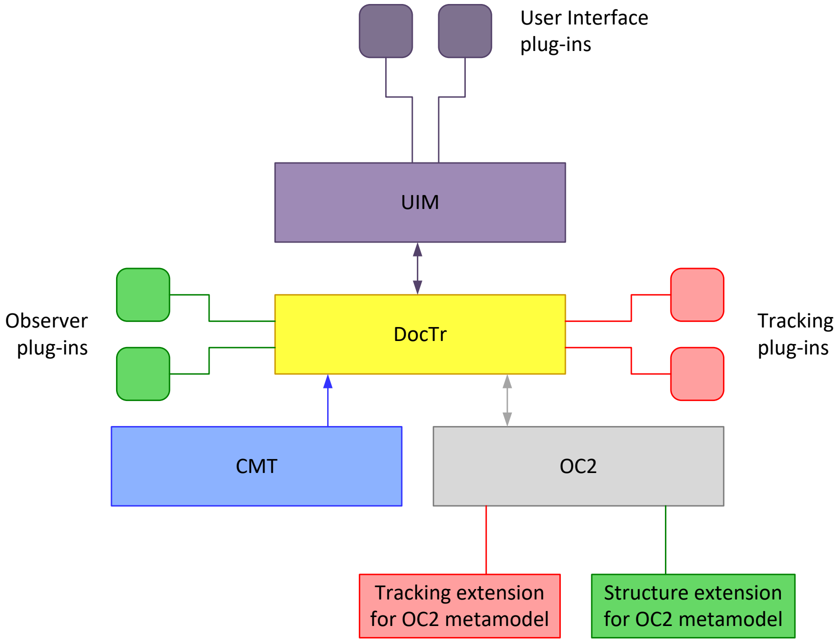



Figure 9.1.: Overview of the architecture of the developed PIM solution

*DocTr*

While physical document tracking solutions are recently gaining attention, existing solutions often show some limitations. They often track physical documents in only one specific type of organisational structure such as piles [67] or physical folders [51]. In addition, the metadata management of tracked documents is forwarded to the application layer which leads to fragmentation and inconsistency when multiple tracking setups are used. In the context of applications that only support digital documents, we can observe that this metadata management is often limited to the presented use case such as simply preserving the positional metadata of a document [39] or contextual metadata [34] and hence not often covering tracking functionality to support all three re-finding cues. In order to overcome these issues, we introduced the DocTr framework which unifies existing tracking setups and provides extensive data management possibilities. With DocTr, documents can be tracked across organisational structures regardless of the used tracking setups. DocTr uses a plug-and-play mechanism to interface with tracking setups to keep track of temporal and spatial metadata of digital and physical documents as well as their organisational structures. The contextual metadata is determined by integrating CMT within DocTr. The tracked metadata is then stored in our OC2 framework [102] designed in our previous work. While our preliminary technical evaluation shows positive results for tracking setups which use error-prone tracking technology, we will have to gain further insights in DocTr's performance in real-life settings. By deploying DocTr in office settings, we will be able to determine how well DocTr can track messy environments (e.g. messy desks) and how error-prone tracking technologies influence DocTr's performance. Furthermore, there is potential to further improve the identification mechanism when multiple versions of an identifier are used by removing the versions that have not been matched for a long time. Finally, in a long-term in-context evaluation, we plan to investigate the usability of DocTr and gain new insights about the trade-off users might make between the required effort to manually give feedback to DocTr regarding unidentified documents and having not up-to-date metadata of their tracked digital and physical documents.

*Context Modelling Toolkit (CMT)*

In order to know which documents or organisational structures have been used during a specific task, we developed the Context Modelling Toolkit. Users can model their tasks by defining situation rules in the form of *"IF situations THEN situation"* rules. For example, the situation `Thesis Writing` can be defined by stating that the `Thesis.tex` has to be opened and that the ring binder with label `Related Work` has to be situated on the desk. Users can also reuse their defined situations to construct more complex situations. However, we designed CMT with the vision to also be a novel solution for end-user programming of any smart environment. From this perspective we defined a multi-layered conceptual model defining how end users, expert users and programmers can work together to enable high customised smart environments. This multi-layered conceptual model together with the fact that end users can define their (complex) situations at runtime is the main contribution of CMT to the field of Ubiquitous Computing. The approach of defining custom new situations and combining them to form more complex situations is well used in other context-aware frameworks which are based on ontologies or probability-based activity recognition. Nevertheless, these frameworks miss the opportunity to let the user define new situations at runtime. Similarly, rule-based context-aware frameworks such as JCOOLS [85] do not offer the possibility to define composed situations at runtime. While the runtime-compilation of a new situation is possible in Dey's Context Toolkit [28], it would require significant error handling since the context rule is encapsulated in the Context Toolkit's situation [30]. However, situations in the Context Toolkit can only have widgets (i.e. sensor data streams) as input and developers cannot reuse situations to compose more complex situations. While there exists some research on visual rule-based programming tools [50, 31], existing solutions do not foresee a distinction between end users, expert users and programmers as well as they do also not provide any mechanism for letting users at all three expertise levels work in synergy. Nevertheless, we also recognise some limitations of our work. While we illustrate the usefulness of CMT by providing various proof-of-concept applications, we did not yet validate the multi-layered conceptual model with end users. Similarly, we still plan to evaluate the given user interfaces for end users and expert users. Finally, it will be interesting to investigate how intelligibility can be introduced in the multi-layered conceptual model as well as to what level the different user profiles require intelligibility.

*User Interface Management (UIM)*

The UIM framework enables cross-media PIM user interfaces to exchange their search state in order to provide users with a consistent augmented environment. Thereby, the UIM framework acts as the controller of our used MVC design pattern where the personal information space's data model is managed by DocTr. The introduction of UIM between DocTr and the user interfaces enables the development of cross-media PIM user interface with a minimal effort with regard to data and consistency management as well as eases the integration of document metadata in existing applications such as the File Explorer. Moreover, our UIM framework follows a publish-subscribe architecture where user interfaces can publish and listen to digital and physical document interactions taking place during a re-finding activity. We defined three channels including one for when a new document has been selected, one for notifying state changes of the filters and one for requesting other user interfaces to show the location of a selected digital or physical document. A similar separation of concerns is taken by the SOPHYA [51] framework where extensibility at the user interface level is also foreseen. However, we must acknowledge that we did not do any scalability and performance testing of the UIM framework. Although the use of a publish-subscribe architecture ensures scalability, the performance might decrease when a user's documents have a large amount of associations with each other since then the intensity of data exchange increases. Additionally, when user interfaces are designed as light-weighted components in existing applications, it might not be the best approach to send all the metadata of the selected document. In the future, we consider to optimise the data exchange process with regard to the support for light-weighted cross-media user interfaces.

### 9.1.3 *Informing the Design of Cross-Media PIM User Interfaces*

The last research question concerned the exploration of the design space for cross-media PIM user interfaces. In order to gain insights into the design space, we developed various proof-of-concept user interfaces which were used during the two exploratory user studies. We first investigated the overall user experience and observed implications with regard to the seamless transition between the digital and physical space. The second user study enabled us to gain in depth insights in the achieved synergy between the cross-media PIM user interfaces and the re-finding mechanism of the organic memory. It further provides a validation of the three main design principles. Finally, the results allowed us to define multiple generic design implications.

#### *Proof-of-Concept User Interfaces*

We showed how cross-media PIM user interfaces can be integrated in a user's digital and physical office environment by developing various proof-of-concept user interfaces where the user interfaces can have interactions with each other. We first presented our graphical PimVis user interface which enables users to explore their unified personal information space by means of contextual and temporal filters. In addition, the position of a digital and physical document is shown in their personal information space. Next, we have designed an augmented filing cabinet which enables users to explore contextual, temporal and spatial relations between folders as well as digital documents by means of a tangible user interface. Finally, we showed some smaller ubiquitous user interfaces such as the File Explorer extension, the Android application and augmented ring binders. A limitation of the designed proof-of-concept user interfaces is the inconsistency in their design regarding the integration of support for the three re-finding cues. In the future, we might investigate to what extent UI and interaction design consistency has to be provided when multiple user interfaces are simultaneously deployed in a user's office environment. While related work such as SOPHYA [51] provides some re-finding functionality in their proof-of-concept applications, this functionality if often very limited. We can also observe the use of the Finder [37] and Window's start menu [34] to integrate metadata of digital documents. However, these examples only show spatial or contextual metadata and thereby lack support for all three re-finding cues.

*The Design Space of Cross-Media PIM User Interfaces*

In the final research phase, we informed the design space for cross-media PIM user interfaces by deploying two user studies. We could observe that participants clearly understood and used the fact that all their digital and physical documents where available in both information spaces. We have seen that they used this knowledge extensively and even used the physical space to search for digital content since it required less effort than using the digital augmentations. In contrast to related work where efficiency and accuracy is given as the main factor influencing the choice of a prosthetic memory [60], our results show that this is not the case in the context of designing prosthetic memory for document re-finding activities. Users place significant value on which prosthetic memory provides the most appropriate triggers for their current reasoning approach (i.e. used re-finding cues) and how many steps in terms of clicks and physical artefact selections their search approach will require with regard to the chosen component in a particular information space. Finally, the results indicate that end-user control of the user interfaces is necessary. Users are not eager to augment every used application or storage artefact since that would be an overkill on re-finding support.

## 9.2 CONCLUSION

While there is a significant body of research to support the re-finding activity of digital documents, less solutions focus on providing similar support for physical documents. Additionally, physical document solutions often focus on the tracking aspect and foresee limited search support besides the position of the document. We have seen that the design of prosthetic memories which support the unification of digital and physical documents is still in its infancy. The unification between information spaces is of significance for the design of prosthetic memory since users use digital and physical documents in a complementary way in their daily activities. Therefore, we proposed the design of so-called cross-media PIM user interfaces which cross the boundaries between digital and physical information spaces. In a first phase, we defined three main design principles for our introduced cross-media PIM user interfaces including support for a seamless transition between information spaces, support for the re-finding mechanism of the organic memory and the integration within a user's constructed organisational landscape. These three design principles can be used as a foundation for further research regarding the exploration of the design space of cross-media PIM user interfaces.

In order to enable the design of cross-media PIM user interfaces we developed three software frameworks. First, the DocTr framework is responsible for tracking and managing the contextual, temporal and spatial metadata of digital and physical documents as well as their organisational structures. The DocTr framework uses our previously designed Object-Concept-Context (OC2) PIM framework to store the tracked metadata. Furthermore, the contextual metadata is determined by our Context Modelling Toolkit (CMT) which has been integrated with DocTr. CMT has been designed based on the multi-layered conceptual model which allows end users to have more advanced control over their smart environment and at the same time offers a balance between automation and manual context modelling. Finally, we presented the User Interface Management (UIM) framework which is responsible for controlling the various integrated cross-media PIM user interfaces in the user's environment. Moreover, it manages the consistency of a user's search state across various user interfaces.

In a last research phase, we have informed the design space for cross-media PIM user interfaces. We first designed various proof-of-concept applications such as PimVis, an augmented filing cabinet and some more ubiquitous examples including File Explorer extensions. These proof-of-concept applications have been used as study platform in our two user studies which allowed us to gain deeper insights in the design space and to validate the three main design principles. The results enabled us to define some generic design implications next to the three main design principles. Moreover, we have seen that users use different re-finding cues across the digital and physical information space, that user interfaces are best integrated in a ubiquitous way in a user's organisational landscape and that users aim to be in control of the integration of the user interfaces in their environment where self-development of the interactions between the user interfaces is crucial.

We presented some foundations for a new generation PIM solutions that work in synergy with the user. Additionally, our technical contributions can be applied within other domains than PIM. For example, the DocTr framework can be used as a unifying data management solution by various applications designed for specific settings including libraries, educational environments or hospitals. Similarly, our presented CMT framework can be used for developing any rule-based logic, for example, in smart environments, business processes or intelligent industrial setups.

## 9.3 FUTURE WORK

Although this dissertation presents extensive work on informing and enabling the design of cross-media PIM user interfaces, we see various opportunities for future work in system design as well as in understanding the design of the introduced cross-media PIM user interfaces.

We can identify future work on different aspects of the DocTr framework. While we have developed an initial user interface to enable users to manage the pending pool (i.e. containing unidentified tracked documents), custom annotations and browse the tracked digital and physical documents, we must still investigate the best design for these interactions.

Furthermore, an in-situ evaluation will indicate where the DocTr framework can be optimised with regard to the identification of documents tracked by tracking setups which use error-prone tracking technologies or which are organised in very unstructured ways such as overlapping piles. Finally, we can investigate how DocTr can be extended to manage knowledge on versioning and how digital/physical copies can be identified as same documents even if they have, for example, distinct annotations.

While we have already mentioned future work with regards to the user interface design and validation of CMT, we see various other opportunities for further improvements. Currently CMT has been designed for single user usage. However, in common smart environments such as smart homes CMT should be able to handle multiple users modelling the same environment. A possible approach can be to enable users to define priorities over rules where, for example, the mother has priority over similar rules defined by the kids. A second improvement of CMT can be the integration of conflict management where conflicting rules should be identified and resolved. Further investigation is required on how conflicts can be resolved, automatically or by involving the user. Finally, we see the future of CMT evolving to a combined use of rule-based reasoning and artificial intelligence. Thereby, we can explore how we can enable users to define situations by the programming by example paradigm where AI techniques (e.g. Learning Classifier Systems (LCS) algorithms) can be used to automatically derive the advanced situation or context rules. This approach can be a user friendly way to define very complex situations. Another approach to decrease the programming effort of end users but still enable them to be in control of the environment can be to enable users to share rule templates on a social media platform. The integration of intelligibility (i.e. why(not) situations are detected) in the overall CMT design would allow users to understand their smart environment and consequently ease the development process. Note that intelligibility in AI techniques is hard to achieve. However, since situations derived by AI techniques would be translated to rules, we can even offer intelligibility when such advanced techniques are used.

Last, we see opportunities for the design of cross-media PIM user interfaces. While we defined some fundamentals of the design space in this dissertation, we still have to gain deeper insights into the design space for different settings and use cases. For example, the design of cross-media PIM user interfaces in an office setting might diverge from the best design in a doctor's office. Additionally, we can explore the use of augmented and virtual reality where the challenges will be to determine how documents should be represented in these realities. Moreover, we can investigate the (dis)advantages of duplicating the real world. More fundamental understandings of the use of the contextual re-finding cue will ease the design for the individual settings and use cases since we have seen that the contextual cue plays a main role in the use of our presented user interfaces. Finally, we might investigate the long-term effects of the use of cross-media PIM user interfaces. Will users rely on prosthetic memories for re-finding and neglect the organisation of their documents (i.e. change their organisational behaviour) or will they only use prosthetic memory as a substitute to gain insights in their personal information space. Finally, we have to see the benefits and drawbacks of our proposed cross-media PIM user interfaces in real-life settings which will teach us more on usability and future opportunities of our envisioned user interfaces.

## 9.4 VALORISATION OPPORTUNITIES

Since we designed the frameworks in a generic and extensible way by means of metamodel oriented programming, they do not hardcode domain specific logic. Thereby, our contributions go beyond the presented work in the field of Personal Information Management and we can identify major valorisation opportunities in other domains.

The DocTr framework can, for example, be deployed in libraries to track paper content as well as to provide a solution to augment paper content with digital media. Cross-media user interfaces can be designed to guide users throughout their library experience by indicating contextual, temporal or spatial relations with other content. The integration of such user interfaces in the real library environment will be a step towards the library of the future where people will be given an immersive experience in content exploration. Besides libraries, our contributions can be used to innovate large companies where employees create a significant amount of semi-structured documents such as notes and reports. These documents are often stored on shared workspaces in the form of folder hierarchies by client or project. The DocTr framework can make these workspaces smart by monitoring the documents' interactions and informing the user that they, for example, have used certain documents in a related task. DocTr can also provide an overview of the workspace, including digital and paper documents, where users can easily explore relations between documents, projects or client. These relations can be automatically created by defining company-specific rules in the CMT framework or users can manually associate documents. Last, the DocTr framework can push the way compliance management is implemented today. Commonly, users are given a role where rules, for example, define the access rights of the user to documents. We can extend this role-based compliance management approach by allowing compliance managers to define access rights based on activities. For example, a user may have a role which forbids them to access the client's financial records. However, when they need the financial records in the context of writing a specific uncommon report, they should be given access. In a role-based approach such a specific access requirement cannot easily be given and often requires role changes which may violate other compliance rules. Thereby, DocTr would save employees time and effort to manage compliance as well as ensures the quality and integrity of the implemented compliance management processes.

Besides the valorisation opportunities of the overall DocTr framework, we can also identify opportunities for the CMT framework as an individual software solution. A first step towards valorisation may be to use CMT in STEM applications. Since CMT offers different levels of rule modelling (i.e. end user, expert user and programmer), youngsters can switch levels depending on their experience. A second valorisation path can be directed to the fact that end-user development is gaining major interests in various settings and domains. For example, healthcare applications that monitor disabled people at home or that provide support to manage treatment are being introduced the last years. Here, CMT can provide a way to allow patient-specific monitoring or support without the need to re-design or highly customise an application. Physicians can define domain- and patient-specific rules where, for example, the healthcare solution company develops the templates or advanced features. Another domain is the introduction of robots in households. Similar to end-user programming of smart homes, CMT can enable end-user programming of robots. In these applications, the robot provider company can define how the robot can do certain actions (e.g. walk or close a door) where the user can then integrate these robot actions in their smart home (e.g. if the door is open then the robot has to close it). Besides such a smart environments, CMT can also be used to model business processes or for supply chain monitoring. While nowadays companies are using highly customised on-premise solutions regarding such a business activities, it requires a large financial effort to always adapt these solutions to a fast changing ecosystem. CMT can be deployed as a SaaS solution where the generic business processes logic can be provided by default for various domains (e.g. facts and rules defined by the programmer). Thereby, companies would be able to highly customise the solution by adding their own business logic to CMT using the end or expert user features. Note that the mentioned valorisation opportunities do not require changes to the software design of the frameworks due to our metamodel-oriented software design. We would only need to further develop the frameworks regarding market-ready optimisations including testing, scalability and performance development efforts.

# Part V

# APPENDIX

# A

# GLOSSARY

CONTEXTUAL METADATA contains information about in which task a user interacted with the document. In this dissertation, it includes interactions such as document access or modifications.

CROSS-MEDIA INFORMATION SPACE is the unification of the digital and physical information spaces. In this information space, digital and physical documents are handled as documents regardless of their information space in the real world.

CROSS-MEDIA PIM BEHAVIOUR describes how users organise and re-find documents across the digital and physical information spaces.

KNOWLEDGE WORKERS are people who daily create and use digital and physical documents in the context of their profession.

ORGANISATIONAL LANDSCAPE describes how a user has organised their digital and physical documents. It includes all created organisational structures across the digital and physical information space.

ORGANISATIONAL STRATEGIES are strategies describing how people create organisational structures. They include filing, piling and mixing.

ORGANISATIONAL STRUCTURES are structures create by people to organise their digital and physical documents. These structures can be files (documents organised in a specific order such as alphabetically and often leads to hierarchical structures), piles (documents placed on-top of each other) and mixtures (semi-ordered documents such as in ringbinders and letter trays).

ORIENTEERING is the act of re-finding a digital document by selecting a folder in the File Explorer and navigating through the hierarchy in a step-wise manner till the needed documents is found. In physical space, orienteering can also be seen as the act of navigating through a pile of physical documents.

PERSONAL INFORMATION is information in the form of documents, notes, websites or photos which an individual keeps with the purpose to use it later in time.

PERSONAL INFORMATION MANAGEMENT is the way how people manage their personal information including keeping, organising and re-finding activities.

PROSTHETIC MEMORIES are digital or physical tools that can be seen as an extension to the organic memory. They often provide support for remembering things later in time when our memory fails.

REFLECTION is the act of looking back to past experiences or activities.

RE-FINDING CUES are cues used by the organic memory to aid recall of information, position of objects or past activities. In the context of re-finding documents, they include the contextual, temporal and spatial cue.

RE-FINDING STRATEGIES describe how people re-find digital and physical documents. The strategies often include the use of one or more re-finding cues.

RE-VISITATION is the act of revisiting the past by accessing previously kept information, objects, photos, etc.

SEAMLESS TRANSITION the act of easily "jumping" between the digital and physical spaces in a way that users do not have to restart their search in the other space.

SLOW TECHNOLOGIES are tools that do not require interactions of users. They provide the user information at particular time intervals. What kind of information and when it is given to the user is automatically determined by the application.

**SPATIAL METADATA** is metadata of a document which describes its position in the environment or organisational structure.

**TEMPORAL METADATA** is metadata of a document that keeps track of when a user interacted with a document. This metadata is formated as key/value timestamps.

**TRACKING SETUP** is a setup including the necessary hardware and software to monitor the temporal and spatial metadata of a document in a specific area in the physical environment such as a desk. In digital space, it is the software that provides interfacing functionality with existing applications such as the File Explorer as well as monitor document changes in these applications.

# B

# TASKS OF THE USER STUDIES

## B.1 USER STUDY: THE SYNERGY BETWEEN PROSTHETIC AND ORGANIC MEMORY

### B.1.1 *Question Sets and Transcript of Audio Fragment 1*

*Transcript of Audio Fragment 1*

0.00 schat ik zet er een taalblad.Radio Taalblad radio voor wie nederlands leert
0.11 vandaag het witloof het witloof heeft de bussel van een cicoreiwortel maar heeft de manieren van een pacha het vraagt immers een zeer bijzondere behandeling jajaja en of het witloof een bijzondere behandeling krijgt
0.24 het filmpje dat je hoorde komt van de website van brusselicious
0.27 en dat is dat is een brussels initiatief dat dit jaar de typisch belgische gerechten in het zonnetje wil zetten zoals witloof dus maar ook brusselse wafels en spruitjes
0.38 er zijn dit jaar allerlei lekkere evenementen in brussel en wie daar alles over weet is martha mesen van
0.44 toerisme brussel hallo martha hallo bart jullie willen met brusselicious een heel jaar lang tonen dat brussel meer is dan spruiten wafels en chocolade e
0.51 ja brussel is eigenlijk heel veel meer dan dat nu natuurlijk euh
0.56 zijn dat wel symbolen die wij hebben gekozen maar brussel is eigenlijk heel diverse in keuken en vooral heel internationaal
1.02 ja inderdaad want je zou dan zeggen je wilt de cliches niet bevestigen maar ze staan wel op de affiches e

1.07 natuurlijk is dat ook omdat het herkenbaar is en iedereen weet ook wel dat euh
1.11 dat de spruitjes en en en mosselen eu typische zaken zijn die wij in brussel eten
1.17 euhm maar het toont ook wel onze humor in een keer want ja brussel viert een jaar lang zijn gastronomie alle wat kiezen wij als symbool voor ons jaar ja wij kiezen ja ja
1.28 de meest gehate groente in de wereld het spruitje euh euhm ja dat toont meteen wij nemen ons eigen niet zo auseriue eu en voila zo zitten wij nu eenmaal in elkaar slaat het evenement eigenlijk aan want het is al een tijdje bezig e
1.42 ja dus brusselicious is een een thema jaar dus eu het is bij manier van spreken op 1 januarie begonnen en het eindigd op 31 december oke nu we zijn vroeg in januarie al begonnen met eu
1.52 eu met het lanseren van de koksmutsen dus wij hebben dan de hele sector uitgenodigd op de grote markt waar we dan het wereldrecord koksmutsen eu
1.59 gooien ale opwerpen en eu verbroken dat moet je uitleggen het het wereld record koksmutswerpen
2.06 het lijkt een beetje op eu die amerikaanse studenten die als ze afstuderen allemaal eu hun hoedje de lucht in gooien
2.14 waardan in dit geval waren het allemaal koksmutsen ja en waren er ook sterrenchefs die dat deden absoluut sterrenchefs eu topchocolatiers eu ze waren allemaal aanwezig en er rijdt ook een speciale brusselicious tram door brussel dacht e
2.28 ja de tram experience en dat is eigenlijk eu 2 uur lang dineren in een tram dus terwijl hij doorheen brussel rijdt euhm
2.38 het dineren is ook wel heel speciaal het eu zijn allemaal gerechten van 2 sterren chefs dus 2 waalse chefs 2 vlaamse chefs en 2 brusselse chefs
2.48 de menus veanderen ook per seizoen en eigenlijk is het dineren en brussel ontdekken tegelijk wat heb je zelf al gegeten op de tram bijvoorbeeld
2.57 eu awel ik eu ik heb toevallig hier het menu voor mij liggen dus eu da was van san degeimbre van l air du temps dus 1 van de waalse chefs
3.05 en ik heb toen een mossel friet zonder friten gegeten dus euhm en daarna een eigentijdse kalfsblanquet zacht gegaard echt dat was super lekker alle ik vond het in ieder geval super lekker en we zijn geeindigd

met een dame blanche
3.22 eu ook heel origineel gebracht ja volgens eu zijn naar zijn signatuur san degeimbre is wel eu
3.29 is 1 van de rijzende sterren in in eu in belgie en en echt terecht ja ja dat is ook een beetje een trend e zo de gewone cliche gerechten nemen en daar dan iets heel speciaals meedoen e ja inderdaad ja en brusselicious is nog lang niet gedaan e waar moeten we de komende maanden zoal naar toe
3.47 eu der is nog vanalles te doen momenteel staan in heel brussel eu standbeelden van eu
3.53 bekende ja eu eetwaren zoals de mossel eu zak frieten chocolade spruiten die allemaal versierd zijn door eu eu kunstenaars en deze zomer worden die allemaal verzameld in het warande park dus eu
4.08 daar kan je zeker al naar toe dan in de zomer krijg je ook iedere zondag de mogelijkheid om te gaan picknicken steeds in een ander park brussel is eu 1 van europas grootste hoofdstede en dat is echt wel de gelegenheid om dat te ontdekken je kan ofwel kom je zelf met je eigen picknickmand ofwel bestel je een picknickmand via onze website of koop je er 1 terplaatse

*Question Set 1 of Audio Fragment 1*

Uit wat blijkt dat de mensen van Brusselicious zichzelf niet zo au serieux nemen?
Hoe wordt witloof beschreven in het filmpje op de website van Brusselicious?
Waarom vindt Martha dineren tijdens de tram experience speciaal?
Wat is de tram experience?
Wat vindt Martha in het algemeen van het dineren op de tram?
Op welke wijzen kan je aan een picknickmand geraken?

*Question Set 2 of Audio Fragment 1*

Welke Belgische gerechten wil Brusselicious in het zonnetje zetten?
Wat is het doel van Brusselicious?
Wat is het doel van het koksmutswerpen?
Waar komen de 6 sterren chefs vandaan?
Van welke chef heeft Martha een menu gegeten tijdens haar tram experi-

ence?
Welke evenementen worden er tijdens Brusselicious zoal georganiseerd?

*Question Set 3 of Audio Fragment 1*

Wie wordt er gebeld door Bart? naam en voornaam
Wat is het doel van de picknick elke keer in een ander park te organiseren?
Wat is het doel van de tram experience?
Van/tot wanneer loopt Brusselicious?
Wat heeft Martha gegeten tijdens haar tram experience?
Waarom belt Bart Martha op?

### B.1.2 *Question Sets and Transcript of Audio Fragment 2*

*Transcript of Audio Fragment 2*

0.00 als je in belgie aan gevangenissen denkt denk je me teen aan overbevolkte cellen
0.05 en aan gevangenen die o p een spectaculaire manier ontsnappen
0.08 maar wist je dat er ook lessen nederlands voor gevangenen worde n gegeven
0.13 wij hebben deze maand in radio taalblad luke vervaet te gast
0.17 hij is een 57 jarige brusselaar die al 5 jaar les geeft in de gevangenis van sint gillis
0.23 in de krant stond onlangs dat ie geschorst is om veiligheidsredenen
0.27 een vreemd verhaal maar wat ons het meest interesseerd is hoe het is om les te geven aan gevangenen
0.34 wel ik zou misschien eerst zeggen euhm dat het gaat om mensen die euhm zich vrijwillig inschrijven voor
0.42 het volgen eu van die lessen dus het is geen verplichting en wat motiveert de gevangene dan waarom zou je als gevangene toch nog lessen nederlands willen volgen
0.52 eu wat ik hen dan vooral probeer als motivering mee te geven is dat je er in brussel voordeel bij hebt
1.00 om eu nederlands te kennen als tweede taal
1.04 omdat dat toch euhm mogelijkheden opent om eu een job te vinden
1.10 om werk te vinden wat voor de mensen die uit de gevangenis komen

een eu
1.16 een heel moeilijke opgave is en als je dus enige kennis van het nederlands hebt dan kan dat helpen
1.23 dat is 1 motivering en een tweede is om zich een beetje te kunnen handhaven in de eu in de
1.30 omgeving van de gevangenis dus da wil zeggen bijvoorbeeld sint gillis is een tweetalige gevangenis dus dat wil dus ook zeggen dat er nederlandstalige gevangenisbewakers zijn
1.42 dat veel van de processen soms in het nederlands doorgaan en dat eu
1.48 de mensen in kwestie er dikwijls geen woord van begrijpen dus
1.52 je hebt er belang bij om euhm ook wat nederlands te kennen oke om te weten wat er over jou beslist wordt is het ook interessant om nederlands te kennen hoeveel lessen per week hebben jouw leerlingen in mijn geval geef ik nu enkel eu
2.08 2 voormiddagen per week in 1 vluegel vleugel a vleugel a wat wilt dat zeggen dat is da zijn mensen die voor de eerste keer in de gevangenis zijn
2.19 die worden gegroepeert in een aparte vleugel wat voor soort mensen krijg je dan in je klas veel van die mensen hebben geen school parcour e
2.27 en een tweede element is dat ik eu mensen binnenkrijg van verschillende nationaliteiten of tenminste van verschillende origine
2.37 die eu soms moeilijkheden hebben met alle talen dat wil zeggen eu normaal geef ik mijn lessen in het frans
2.46 maar er zijn dan bijvoorbeeld ook mensen die geen frans begrijpen zie je
2.50 dus eu dan moet ik dat een beetje aanpassen met wat engels der tussen te gooien en om toch nog zo toch tot het nederlands te komen dat is duidelijk niet gemakkelijk hoe ga je daarmee om je moet weten
3.01 de omstandigheden zijn zeer moeilijk e er is ten eerste de omgeving van de gevangenis er bevind zich natuurlijk geen bewaker in de klas maar eu
3.10 de bewakers zijn wel alom aanwezig en zijn present jaja mocht er iets gebeuren
3.16 mocht er iets gebeuren wat mijn nog nooit overkomen is maar goed dat dat is daar dus wel en dan hebben we tentweede natuurlijk
3.23 al de problemen waarmee de mensen zitten het is dan ook een situatie e die de mensen kompleet lusteloos maakt je moet voor niks

zorgen
3.30 alles word beslist in jouw plaats en dus dat element van het afnemen van iedere verantwoordelijkheid voor what ever voor wat ook
3.39 dat is eu volgens mij heel wat nefaste bijwerkingen van eu een gevangenissysteem ma dus daar heb je daar heb je dus wel mee te maken als je leraar bent hoe moeilijk is het om les tegeven om die mensen echt iets bij te brengen iets te leren
3.52 ik heb mensen gehad die onder mekaar nederlands begonnen te spreken op
3.56 de eu in de tijdens de wandeling oo mooi maar dat is wel vrij exceptioneel vrij uitzonderlijk
4.02 maar wat jij dan doet is hen toch eu proberen ja nuttig bezig te houden
4.07 ja dat is waar ik denk dat dat voor een aantal gevangenen ook echt ook een lichtpunt is e ze zien iemand van buiten
4.12 zonder uniform iemand uit de normale wereld euhm tja

*Question Set 1 of Audio Fragment 2*

Aan wat denken, volgens de interviewer, de meeste mensen als ze aan gevangenissen denken?
Welke 2 talen worden er in de gevangenis van Sint-Gillis gesproken?
Waarom vindt Luke het belangrijk dat gevangenen in de gevangenis van Sint-Gillis nederlands kunnen spreken?
Wanneer geeft Luke les in de gevangenis van Sint-Gillis?
Waarom worden gevangenen lusteloos volgens Luke?
Zijn er bewakers aanwezig in de klas?

*Question Set 2 of Audio Fragment 2*

Waarom vindt de interviewer het les geven aan gevangenen duidelijk niet gemakkelijk?
Waarom zou je als gevangene les moeten volgen volgens Luke?
In welke gemeente woont Luke?
Wat doet Luke als een gevangene in zijn les ook geen frans spreekt?
Noem een van de nefaste bijwerkingen van ons gevangenissysteem.
Waarom is Luke opgelucht als het gaat over het feit dat er geen bewakers in de klas zijn?

*Question Set 3 of Audio Fragment 2*

Is het normaal dat gevangenen nederlands onder elkaar beginnen te spreken?
Waarom zien een aantal gevangenen Luke als een lichtpunt?
Hoe vindt Luke de omstandigheden waarin hij lesgeeft?
Wat is de achternaam van Luke?
Hebben alle gevangenen in Luke zijn klas hun school afgewerkt?
Waarover gaat het interview?

### B.1.3 *Question Sets and Transcript of Audio Fragment 3*

*Transcript of Audio Fragment 3*

0.00 stefan engels is een gentenaar en hij loopt elke dag rond de watersportbaan
0.05 een grote waterplas is dat net buiten de stad
0.08 nu hij is daar helemaal niet alleen er zijn daar wel meer mensen die een rondje komen lopen
0.13 maar stefaan is wel een hele speciale loper want hij doet het elke dag en hij loopt verdorie elke dag een volledige marathon dag stefaan engels
0.23 ja dag marcel das wel heel speciaal e wat doe jij precies
0.26 ja lopen e vooral lopen e mijn e ik heb een voltijdse job lopen dus eum dus jij loopt elke dag een marathon das
0.33 42 kilometer denk ik mmh ja 195 meter ja ja ja je gaat dus elke dag 42 kilometer en 195 meter lopen
0.41 en je gaat dat 365 dagen volhouden dus een heel jaar als ik het goed begrijp dat is de uitdaging ik ga dat nog niet op papier zetten met de bevestiging dat ik dat zou kunnen
0.50 euhm we zijn vandaag aan dag 12 dus vandaag om half 4 start ik voor mijn twaalfde marathon
0.56 en zo gaat dat verder ik ben elke dag blij dat ik een dagje verder sta
1.01 ja wat wil je er precies mee bereiken want dit is wel een hele grootte inspanning e ja wel wat ik bereik is dat ik de media kan krijgen dat is bij deze gebeurt inderdaad dank u bij deze leuk dat jullie mij bellen
1.12 ik had een boodschap eu ik ben eu ik voel mezelf een beetje de man de man met een missie mijn missie is dat eu

1.20 bewegen zo belangrijk is in het leven bewegen vitaal we gaan allemaal een beetje vitaler moeten worden als je vitaler zijt dan is je levenskwaliteit hoger
1.29 ben je ook minder ziek en al dat soort zaken de meeste mensen weten dat wel dat gezondheid
1.34 o zo belangrijk is want we wensen het mekaar ook allemaal toe in het begin van het jaar
1.38 euhm ma hoe doe je dat ja awel ja tis eenvoudig door wat meer te bewegen wat beter op uw voeding te letten
1.43 ik wil het voorbeeld zijn ik wil mensen eu een beetje uit hun
1.46 luie zetel halen door ze te inspireren je bent op 1 januarie begonnen en je hebt intussen 12 marathons gelopen
1.53 hoeveel toertjes rond de watersportbaan zijn dat precies ja de watersportbaan is 8 is 5 kilometer exact rond dus 8 keer en half e
2.01 daar komt het op neer ja ben je nogaltijd even fris als op dag 1
2.05 nee nee helemaal niet die eerste week was heel zwaar ik dacht dat ik goed voorbereid was ik heb mij een jaar op toegelegd om om mijn lichaam te laten gewennen dat ik elke dag 4 uur eu
2.14 moet lopen euhm en ook het snelle recupereren maar het was een moeilijke week ook door de extreme koude
2.21 euh heb ik toch wel wat euh op mijn tanden mogen bijten om om vol te houden maar de laatste dagen gaat het al weer wat beter maar het is ook ja euhm
2.30 opladen e mentaal ook want kijk ja ik ben nu eu ik heb een hotelkamer met uitzicht op de torens van gent
2.38 waar ik euhm een halve dag ben om volledig tot rust te komen vertel is want jij bent een gentenaar je woont dus in gent en toch heb je een hotel kamer waarom woon je niet gewoon thuis dit jaar ja ik heb een mooi aanbod gehad van het hotel harmonie eu dat is pal in het centrum van de kraanlei
2.56 en daar heb ik eu kunnen een mooie kamer eu op het hoogste verdiep met uitzicht op de 3 torens en daar eu
3.01 daar vertoef ik in mijn groot bad en in mijn goed bed waar daar rust ik uit en kan ik mij een beetje wegsteken van de eu
3.10 van de buitenwereld die mij soms eu overrompelt met heel veel vragen enzo
3.15 dus maar is er dan nog tijd voor je vrouw en kinderen ik weet niet of je die hebt natuurlijk ik heb een vriendin wat vind die ervan want die

gaat jouw een heel jaar
3.22 niet veel zien denk ik ja dat valt wel mee e ik ben eu ik loop 4 uren voor de rest van de dag ben ik eigenlijk eu
3.29 aan het rusten dus eu ik heb vanmorgen ook de afwas gedaan en eu
3.34 en ik slaag ook nog een dweiltje in het huishouden dat is juist hetgeen ik wil aantonen eu het is een job gelijk een ander alleen ik heb wel een jaar geen weekends en verlof eu
3.44 dat is dan het enige verschil en en mijn vriendin loopt ook uiteindelijk we hebben mekaar zo leren kennen tijdens het lopen ha das leuk om te weten
3.52 vertel eens hoe ziet jouw dag eruit euhm sta je op een vast uur op of hoe gaat dat ja ik probeer euhm
3.59 ik probeer tussen de 8 en 10 uur te slapen e meestal lukt dat niet 10 uur maar alle 8 8 zit er dik in
4.05 en dan neem ik een zeer lang ontbijt eu ja veel granen eten veronderstel ik veel energie opdoen ja granen eu fruit
4.13 heel veel broodproducten vooral brood enzo en beleg het maakt eigenlijk niet uit massa ik prop mij vol en dan eu
4.19 ga ik naar de kinee de kinee doet kinee alles goed losmaken en dan afhankelijk wanneer dat ik start met de marathon
4.26 eet ik nog eens een pasta maaltijd en dan eu ja begin ik te lopen e

*Question Set 1 of Audio Fragment 3*

Waarover wordt Stefaan geinterviewd?
Waar gaat Stefaan lopen?
Waarom gaat Stefaan naar de kine?
Hoeveel rondjes rond de waterplas is gelijk aan de afstand van een marathon?
Waarom vond Stefaan het lopen erg lastig de eerste week?
Hoeveel uur slaapt Stefaan gemiddeld?

*Question Set 2 of Audio Fragment 3*

Hoeveel uur loopt Stefaan dagelijks?
Welke huishoudelijke taken doet Stefaan zoal?
Wat is het doel van Stefaan?
Hoe voelde Stefaan zich na de eerste paar marathons?

Waarom heeft Stefaan ook een hotelkamer?
Hoeveel meter is een marathon?

*Question Set 3 of Audio Fragment 3*

Waarom heeft Stefaan de eerste week op zijn tanden moeten bijten?
Wat eet Stefaan als ontbijt?
Wanneer gaat Stefaan vandaag lopen?
Wat is de missie van Stefaan?
Welk uitzicht heeft de hotelkamer in Gent?
Waarom vind Stefaan bewegen zo belangrijk?

*Grading Example for Audio Fragment 3*

This answer to the following question got graded 3 since it does not include all keywords (or synonyms) and context.
Question: Hoe voelde Stefaan zich na de eerste paar marathons?
Answer: *Slecht omdat het slecht weer was.*

This answer to the same question question got graded 5 since it does include all keywords (or synonyms) and context.
Question: Hoe voelde Stefaan zich na de eerste paar marathons?
Answer: *Niet goed. Hoewel hij goed voorbereid was heeft hij het snelle recuperen wat onderschat. Het was ook slecht weer die eerste week.*

## B.2 USER STUDY: UX AND THE SEAMLESS TRANSITION

### B.2.1 *Tasks Without Cross-Media Support*

Open the folder publications/ITS.
During the tasks you can use the tabletop, Windows Explorer and any document in the bookcase.
Your current task is "ITS Paper Writing"

Task 1: You want to read the paper "Reality Editor". This paper is related to the paper called "Objectop" which you have used in your current context/task and is stored in the "papers" folder in the current directory.

Task 2: You want to store a paper in your "papers" folder which is about "DocuDesk". You remember that the paper was used during a meeting with Audrey. The paper is also stored in her folder. Copy the paper to the "papers" folder in the directory in which you are currently working.

Task 3: Find the image with the "LED" that you have taken while working on the Cool Office project. Which documents are related to this image? Open the image on the desktop.

Task 4: Find your notes where you have written "general contexts" at the top of the page. You have used it previously when writing this paper. Go back to the desktop and google "Holidays".

Task 5: You need to cite another paper which is about "PaperSpace". This paper is related to the paper called "WatchConnect" which you have used in your current context and is stored in the "papers" folder.

Task 6: You want to add a comment to your physical copy of the paper about "StackTop". The paper is used when writing this paper. Find the paper in the bookcase.

### B.2.2 *Tasks With Cross-Media Functionalities*

Open the folder publications/UIST2015.
During the tasks you can use the tabletop, Windows Explorer and any document in the bookcase.

Task 1: You want to read the paper "iCap". This paper is related to the paper called "Lee2013" about a "Tangible programming tool" which you have used in your current context and is stored in the "paper" folder which is in the current directory.

Task 2: You want to store a paper which is about "Improving Intelligibility and Control in Ubicomp" by Jo Vermeulen. You remember that the paper was used during a meeting with Wouter. The paper is also stored in his folder. Copy the paper to the “papers” folder in which you are currently working.

Task 3: Find an image with Vince where his face is shown and is taken in DisneyLand. Open the image on the desktop.

Task 4: Find your notes where there is written “Layers of Abstraction” at the top of the page. You have used it previously when writing this paper. Find the paper in the ring binders. Go back to the desktop and google “End users”

Task 5: You need to verify some details which are in the “Drools Manual”, you have used it during the development of the CMT tool. The manual is related to the paper called “Park2013” which you have used in your current context and is stored in the “papers” folder.

Task 6: You want to add a comment to your physical note where you have written “Corrected Schema” at the top. The note is used when writing this paper. Find the note in the bookcase.

## B.3 USER STUDY: UNDERSTANDING THE USER’S INTERACTIONS

### B.3.1 *Tasks Using the Context Mode*

Task 1: The digital documents of the “PimVis” project are stored in the MyDocuments/Research/PimVis folder. Open the folder in the File Explorer. Search and open the digital document “PimVisPaper.pdf”. You remember that you have also used the image “bubblePicture.png” during the writing of the needed paper. This image is stored in the abovementioned PimVis folder.

Task 2: You need the physical folders related to the “CoolOfficeProject”. You know that Anna worked on the CoolOfficeProject. Show the physical folders which have been used during the CoolOfficeProject. The folder

"Karger" was also used in a meeting with Anna.

Task 3:
a) You need an image of the Note4U application. Search and open the image "imageApp.png". Of course, you used the image during the "Note4U" project. Start your search by selecting the physical folder with the label "Collins".
b) Show the physical folders which you used during the writing of the Note4U paper. There is a context "WritingNote4UPaper" and the previously opened image was also used during the writing of the paper.

Task 4: You can choose where you start your search in the File Explorer, the sidebar application or the filing cabinet.
a) Show all physical folders which are used during the meetings with Bart (context is "BartMeeting"). You remember that you used the physical folder "Petrelli" during a meeting and the digital document MyDocuments/Proposals/IWT/proposal.pdf.
b) Open the digital document "FwoProposal.pdf". You have accessed the folder "Whittaker" and the digital document MyDocuments/Research/-CoolOffice/Software.pdf during the writing of the proposal (context is "FwoProposal").

### B.3.2 *Tasks Using the Temporal Mode*

Task 1: The documents of the "PimVis" project are stored in the MyDocuments/Research/PimVis folder. Open the folder in the File Explorer. Open the digital document "Guidelines.pdf". You know that you have used this document in the same week as the digital document "Draft.pdf" which is stored in the PimVis folder.

Task 2: Show all physical folders which have been used in the same month as the folder "Bellotti".

Task 3:
a) Open the digital document "CHI2016.pdf". You have used the physical folder labelled "Bellotti" within the same hour.

b) Show the physical folders which have been used within the same week as the "intro.tex" digital document. The document is stored in the same digital folder as the document "CHI2016.pdf" which you used in task 3.a.

Task 4: You may choose where you start your search in the File Explorer, the sidebar application or the filing cabinet.
a) Show all physical folders which you have accessed during the same week as the document MyDocuments/Research/PimVis/Paper/introPimVis.tex or the physical folder "Katefori".
b) Show all digital documents which you have used the same day as the physical folder labelled "Karger" or the document MyDocuments/Research/PimVis/Paper/IntroPimVis.tex.

### B.3.3 *Tasks Using the Spatial Mode*

Task 1: Search and open the digital document "SpaArrangement.pdf".

Task 2: Show all physical folders which start with a "D".

Task 3:
a) Start in the digital sidebar application. Show the physical folder labelled "Haller".
b) Start in the filing cabinet. Open the digital document "reviews.pdf".

Task 4: You may choose where you start your search in the File Explorer, the sidebar application or the filing cabinet.
a) Show the physical folder labelled "Dix"
b) Open the digital document "CoolStuff.pdf"

### B.3.4 *Tasks Using All Mode*

Task 1: The documents of the "PhDThesisWriting" project are stored in the folder MyDocuments/Research/PhDThesisWriting. Open the folder in the File Explorer. You can use all modes. Search and open the digital document "Note4UPaper.pdf". You know that you used this document within the context "WritingNote4UPaper" and that during the paper writing you also used the document "Chapter2.pdf" stored in the above-mentioned PhDThesisWriting folder. You also remember that you used the document "Note4UPaper.pdf" the same day as the "Chapter2.pdf" document.

Task 2: Choose one of the three assignments:
a) Show all physical folders which you have used the same day as the folder "Sellen".
b) Show all physical folders which you used during the "ArtVis" project. You remember that Tom also worked on this project and that you accessed the folder "Sellen" during a meeting with Tom.
c) You need a physical folder which you have used previously in another task. You remember that the folderâĂŹs label starts with an "F". Show all possible folders.

Task 3: Choose one of the three assignments a), b) or c):
a) Show all physical folders which you have used the same day as the document MyDocuments/Stuff/BillPimVis.pdf.
b) Show all physical folders which start with a "D". You have to use the sidebar application on the desktop.
c) Show all physical folders which you used during the "PimVis" project. You remember that you stored the bill of the conference where you presented PimVis in the folder MyDocuments/Stuff
Second part of task 3
d) You need the digital document "PhDThesis.pdf". You remember that you have accessed the document on the same day as the physical folder "Sellen" and that you used the physical folder "Sellen" during the writing of the PhD Thesis

Task 4: You may choose where you start your search in the File Explorer, the sidebar application or the filing cabinet. Choose one of the three assignments a), b) or c):
a) Show all physical folders which you have accessed during the same month as the digital document MyDocuments/PhDThesisWriting/slides.pptx or the physical folder labelled "Whittaker".
b) Show all physical folders which are used during the PhD thesis presentation (context is "PhDPresentation"). You remember that you used the physical folder "Whittaker" and the digital document MyDoc-

uments/Research/CoolOffice/Qrcodes.pdf during the creation of the presentation.
c) You need a physical folder which you have used previously in another task. You remember that the folder's label starts with a "J". Show all possible folders.
Second part of task 4
You may choose where you start your search in the File Explorer, the sidebar application or the filing cabinet. Choose one of the three assignments d), e) or f):
d) You need a digital document which you have used previously in another task. You remember that the document's label starts with a "D". Show all possible documents.
e) Open the digital document "ObjectTop.pdf" which you used during the "CoolOfficeProject". During the project, you have also accessed the physical folder labelled "Sellen" and the digital document Documents/Research/CoolOffice/Desk.pdf
f) Show all digital documents which you have accessed during the same week as the document MyDocuments/PhDThesisWriting/Chapter3.pdf or the physical folder labelled "Dey".

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