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A Tool for Episodic Memory Reflection Based on Implicit Diary Entries

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Abstract

Paper or digital diaries are usually used by people to record their everyday life. Diary entries can be revisited at any time and hence help people to recall previous days. The information in diaries is mostly created explicitly. By manually capturing personal related information, it can be difficult for users to decide which information is important to record. Furthermore, it is difficult or impossible for persons to observe all their behaviors. Therefore, by manually recording diary entries, some valuable information can be left unrecorded. On the other hand, mobile devices, like smartphones and tablets, can automatically collect a variety of personal related information. In the last few years, many wearable devices have appeared on the market, that support automatically tracking of personal information including user's sleep and movement behavior. Data collected using these devices can be used to augment the information in diaries. Reviewing diary entries, which can also be used as memory cues can facilitate people to recall previous events. In this work, we explored whether reflection on implicit recorded personal information affects recall. We built an Android application that implicitly collects personal related data and prompts users to reflect on them. Furthermore, the application provides users the opportunity to quiz themselves about the collected data. We conducted a study with 11 participants, and the application generated overall more than 7000 recordings. We found that reflection improves recall of implicitly recorded personal information. Furthermore, we reported the automatically captured information types that are effective to support the recall of previous days.

List of Abbreviations

API Application Programming Interface

ID Identifier

JSON JavaScript Object Notation

PHP PHP: Hypertext Preprocessor

REST Representational State Transfer

SDK Software Development Kit

SMS Short Message Service

SQL Structured Query Language

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1 Introduction

Episodic memory is a memory that enables to re-experience past events which occurred in the particular time and place. Since episodic memory supports people to have a feeling of continuity and a sense of self, it has an important factor for the perpetuation of the quality of life [LD07]. Various tools are used to support episodic memory. These tools usually deal with recording personal information and preparing that information for reflection purpose. More and more daily life activities and events are recorded using paper diaries, online tools (*e.g.* social networks and journaling tools), mobile phone applications and lifelogging devices. Data collected using these tools contains valuable information for *self-reflection* and can be used as a memory aid. Furthermore, people are interested in self-reflection since ancient times. Ancient Greeks were greeted with the inscription "*Gnothi seauton*" or "*Know thyself*" in the Temple of Apollo at Delphi [LDF10].

Some people keep diaries as a self-reflection tool. Diaries enable people to find and review previously recorded entries at any time. Such a tool can be used to record personal information, such as daily experiences, thoughts, feelings, insights, opinions and recollections. Writing diaries facilitates people to navigate through recorded personal information and reflect on them. Reflection can occur during writing new entries or reviewing the old ones. Reviewing diary entries, which can also be used as *memory cues* facilitates people to recall past events. On the other hand, reflection on diary entries can help people to gain a greater understanding of past events [BKM+14]. On top of that, keeping diaries has several other benefits. Enhanced personal growth and development, improved ability of self-expression and problem solving, and improvements in physical and psychological health are some of them [Hie01].

Diary entries are usually created explicitly. People need spend time and have the motivation to write something in diaries. However, it is not always possible to enter all personal information in diaries. Sometimes the author of a diary does not have enough motivation or time to record particular information. Furthermore, it is not always possible to be aware of the importance of events when they are occurring. Thus, some information is forgotten to write or not detailed described in diaries.

Having the possibility to collect personal information implicitly can assist diarists to solve these problems. Mobile devices, like smartphones and tablets, are automatically capable of collecting a variety of personal related information. It is possible not only to record users' communication behavior but also to collect their physical activity data by using the sensors in smartphones. Moreover, in the last few years, many wearable devices have appeared on the market that can be used for *quantified-self* purposes. These devices can automatically collect personal related information, including sleep behavior, physical activity, heart rate even without user's interaction. Moreover, wearable cameras like Narrative Clip [1] enable automatic capturing interesting moments which can then also be used as a diary entry. Collecting personal related data implicitly allows recording of such experiences that are even not easily observable to users (*e.g.* sleep behavior). The data gathered using such devices can further be enriched with other contextual information, such as time and location to provide rich memory cues to support the recall of past experiences. Furthermore, reflection on the collected personal information assists people to recall past events, provides new insights into past moments and encourages positive behaviors [BKM+14].

The aim of this master thesis is to investigate how reflection on implicitly collected information can affect recall and what kind of automatically recorded information is more effective for recall. For this purpose, an application for Android devices is implemented that automatically collects personal data and invites users for reflection. The application records various personal data, including user's communication behavior, location and calendar data. Furthermore, user's movement and sleep behavior are also ascertained using a wearable device. On top of that, we conduct a user study to investigate the impact of reflection on implicitly collected information on the recall. The findings can facilitate the development of tools that automatically record personal related information to support episodic memory.

1.1 Structure of this Thesis

This thesis is structured as follows:

Chapter 2 – Related Work and Background: This chapter deals with the basic information about episodic memory, memory cues and reflection. Furthermore, it discusses several related work regarding reflection.

Chapter 3 – Concept: This chapter illustrates the concept of the work. It presents the application proposed to investigate the impact of reflection on implicit collected data on recall.

Chapter 4 – Implementation: In this chapter, we discuss the implementation of the ReflectiveDiary Android application and a server. The server deals with the database that stores the log data for the evaluation.

Chapter 5 – Evaluation: The chapter introduces the conducted user study. Here we give information about participants and discuss the design and procedure of the study.

Chapter 6 – Results: In this chapter, we analyze the data collected during the study and discuss the results of the evaluation.

Chapter 7 – Conclusions: This chapter summarizes the work, draws a conclusion and finally presents ideas for future work.

[1] http://getnarrative.com, last visited on March 30, 2016

2 Related Work and Background

In this thesis, we attempt to implement a tool that supports episodic memory. This tool must implicitly collect personal related data and prompt users to reflect on them. In order to build such a tool several background information have to be studied. Furthermore, related work supporting reflection on personal data and recall of episodic memories must be deliberated.

This chapter deals with the related work and background information on recall and reflection. First, *episodic memory system*, its properties and relation to semantic memory system are briefly described. Afterward, *memory cues* are introduced that are used in previous work to support the recall. Finally, previous work related to the benefits of *reflection* is discussed.

2.1 Episodic Memory

Human memory is a complex system. In the literature, two kinds of memory are distinguished: *declarative* and *nondeclarative* [Squ04]. The nondeclarative memory contains several kinds of memory systems, including procedural, priming and perceptual learning, simple classical conditioning and nonassociative learning memory. On the other hand, the declarative memory is a memory of facts and events. It enables us to consciously recollect and compare memory elements. Furthermore, the declarative memory supports us to create relationship among memories. Since the declarative memory is representational, it allows the modeling of the external world [Squ04].

Descriptive memory system can be further divided into *semantic* and *episodic memory systems*. The semantic memory is a memory of facts. It stores the knowledge about the world. Tulving [Tul72] describes the semantic memory as a memory that is necessary to use the language. The semantic memory of a person stores all knowledge about the words that he knows, including their meanings, relationships among them, and rules and methods to manipulate these words and relations. After retrieval of information from this memory system, the information stays unchanged in the memory. The information handled in semantic memory does not contain any personal experience. For example, the following information belongs to the information handled in the semantic memory: "I remember that the capital of Germany is Berlin." This statement is a fact and remembering this information does not change the content in the semantic memory.

On the other hand, episodic memory deals with the information that refers to a personal experience [Tul93]. The episodic memory system enables a person to remember a particular event that experienced in the certain place and time. It allows people to mentally time travel and consciously re-experience past occurrences [Tul93]. The following statement is an example of information that can be handled by the episodic memory system: "I remember staying in Berlin for a week during my summer holidays last year." The statement is a personal experience that can be recollected in its spatial-temporal relationships to other alike events. Retrieval of information stored in the episodic memory system makes at the same time special input to this memory system. Therefore, each retrieval modifies the content of episodic memory store [Tul72].

Conway [Con09] proposed several properties of episodic memories. Episodic memories are often represented in the form of visual images, and these memories preserve their temporal order. Furthermore, episodic memories have always either field or observer perspective. Field perspective in visual episodic memories is considered to be the viewpoint of a person that remembers. It was found that visual episodic memories with field perspective are more strongly associated with recollective experience than the memories with a third-person perspective. However, episodic memories are not always recalled. One can easily recall an event experienced an hour ago. Nevertheless, as time passes, access to old episodic memories get lost. Nonetheless, several memory cues can be provided to persons to help them remember, at least partly, previously inaccessible episodic memories.

The episodic memory system is evolved out of the semantic memory system [Tul93]. Thus, some operations of it depend on the semantic memory system. However, episodic memory is not necessary for semantic memory to store and retrieve information. Children can learn facts of the world before they are able to make use of knowledge about their personal experiences. It shows that the episodic memory develops later in childhood than the semantic memory [Tul93].

2.2 Memory Cues

The aim of this work is to find out how reflection on implicitly collected personal information can affect recall. However, before one can reflect on own personal information is important that that information is collected and consists of richly recalled memory cues. As discussed in the previous chapter, retrieval of information from episodic memory causes alteration of that information in the episodic memory store. Tulving [Tul84] proposed that retrieval of information from the episodic memory system occurs through a synergistic combination of information in the memory and provided retrieval cue. Furthermore, in the same work, he suggests that the retrieval query for information in the episodic memory is the following: " *What did you do at time T in place P?*" That being the case, memory cues providing information about persons participated in an event or performed an activity, the context, the location and the time of that event or activity can enhance recall [GK13]. Various memory cues are investigated in previous work to support episodic memory. The following chapters discuss some of them.

2.2.1 Visual Cues

As already discussed in chapter 2.1, visual images are the dominant form of representation of episodic memories. Hence, images can provide plenty of information for recall. By looking at a picture, one can not only see objects but also guess relation among them. Therefore, images can contain several cues to trigger recall.

Lee and Dey [LD07] categorized four different types of cues in photos that trigger recollection. They are *person*, *object*, *place* and *action* cues. In the same work, Lee and Dey discuss characteristics of good memory cues. First, if one does not recognize persons or objects in a photo, those cues will not help him to recall the original experience. Therefore, effective visual memory cues have to contain *recognizable* content so that they assist remembering of similar experiences. Second, visual memory cues that represent *distinctive* details help people to remember those unique experiences. Unusual or unexpected details in memory cues can be more memorable than those usual for people's normal expectations. Thus, photos that contain distinctive elements can be used as effective memory cues. Finally, visual memory cues that hold details with *personal meaning* are more effective in triggering the recall. Personal significant cues are tended to be more recognizable and memorable. Therefore, it is also an important characteristic of good memory cues.

Wearable cameras can be used to collect visual cues. These devices are mainly worn around a user's neck or head-mounted and capture automatically photos from the person's original perspective. Since memories with the field perspective are more strongly associated with recollective experience than the memories with observer perspective, visual cues collected using wearable cameras can be effective in supporting the episodic memory [Con09, GK13].

2.2.2 Location Cues

In contrast to visual cues that support episodic memory with rich information, location cues support remembering through allowing people to reconstruct habits in their behavior [KSWK10]. These memories are inferential. One can reconstruct a memory from location data even being not able to recollect it. For example, one can conclude that he attended a particular event a year ago because of location cue, even if one can't actually recollect it. However, using location cues as a contextual information for visual cues can assist people to recall more events [KSWK10]. Nevertheless, prior work [WKP+12] suggests that in order to provide distinct cues, location information needs to vary significantly. For example, providing many photos as a memory aid that are taken either in the home or at work reduces distinctness of location information. In this case, the information about places does not help much by recalling the experience represented in the photo.

2.2.3 Temporal Cues

Episodic memories keep track of the temporal order of occurrence of personal events [Con09]. Therefore, preserving the temporal order of memory cues can support remembering. Furthermore, temporal cues about a particular event can help people to recall temporally surrounding events [GK13].

People tend to recall their memories in temporal order. An event can be retrieved from memory either by recalling a distinctive detail about it and then accessing subsequently other details or by accessing knowledge sequentially from details of first-occurring activities to last [CPP00]. In both cases, after accessing the knowledge first time, further memory details are retrieved in order of their occurrence. However, Whitten and Leonard [WL81] reported a case where people were more efficient when they recalled information in the backward order. In an experiment, they asked students to recall the name of one teacher from each of 12 preuniversity school years using forward (Grades 1-12), backward (Grades 12-1) or random order. The results of the experiment showed that searching information through autobiographical memory in backward order is more efficient than forward-ordered or random-access search.

2.2.4 Audio Cues

A few studies investigated sonic mementos to support episodic memory. Oleksis and Brown [OB08] presented Sonic Gems. The Sonic Gems prototype consists of a bowl and objects with RFID (Radio Frequency Identification) tags attached to them. The RFID tags enable to link audio memories to these objects. The objects are placed in the bowl that has an RFID reader attached to it. Each time when an object is taken out of the bowl, the sonic memory is triggered. The evaluation of the Sonic Gems showed that listening audio recordings assists people to mentally re-experience the moment that the sound has originally been recorded. Furthermore, audio recordings trigger not only memories but also associated feelings.

Petrelli *et al.* [PVK$^+$10] designed FM Radio (Family Memory Radio), an old fashion radio embedded with technology for uploading and playing back sonic memories. The FM Radio was evaluated with families that used the device to access and listen to sonic mementos of their previous year's holidays. The results of the evaluation showed that the FM Radio reminds users about their sound and affords collective interaction with digital belongings, and hence solves the inaccessibility and invisibility problem with digital collections.

2.2.5 Olfactory Cues

Several related work investigated odors as memory cues. In a study Herz and Schooler [HS02] compared the emotional and evocative qualities of autobiographical memories evoked by odors and visual cues. The results showed that memories evoked by olfactory cues are more significantly emotional than those evoked by the visual or verbal representation of the same cue.

In another experiment, memories elicited by olfactory, verbal, visual, tactile and musical cues were compared [Her98]. The results of the experiment revealed that the accuracy of memories elicited by odors is equivalent to that of memories evoked by the other cues. Furthermore, odor-evoked memories are more emotional than memories mediated by visual, tactile, musical or verbal stimuli.

2.3 Reflection

There are a variety of definitions for *reflection* in related work. Reflection is defined as "*an important human activity in which people recapture their experience, think about it, mull it over and evaluate it*" [BKW13, p. 19], "*reviewing a series of previous experiences, events, stories, etc., and putting them together in such a way as to come to a better understanding or to gain some sort of insight*" [BKM+14, p. 94], "*looking at lists of collected personal information or exploring or interacting with information visualizations*" [LDF10, p. 562]. From all these definitions we can conclude that recording and presentation of information, such as previous experiences, stories, events are important factors for reflection to occur. Reflection can be short-term or long-term [LDF10]. In the short-term reflection, collected personal information is presented to the user right after the capture. Such a reflection enables users to appreciate their current status. For example, one can use a fitness tracker that displays the number of steps taken in a day. By reflecting on this information, the user can monitor progress towards achieving his movement goal. On the other hand, the long-term reflection allows users to observe changes in their collected personal information over a period of time. In this case, users reflect on their personal information after several days or weeks past the date information was recorded. For example, by reflecting on their movement data of last three weeks, people can compare the number of steps taken each week to monitor the progress of their movement behavior.

Some conditions must be fulfilled for reflection to occur. Primarily, reason or an encouraging factor is necessary for people to come to reflection [FF10]. Baumer [Bau15] focuses on breakdown and inquiry as a support to facilitate reflection. He emphasizes that breakdowns, such as doubtful, uncertain, or unusual situations can be an encouragement for people to come to reflection. Additionally, an inquiry can support reflection since it concentrates on reviewing a series of previous experiences. Secondly, for the reflection, it is assumed that personal information has already been collected and prepared for illustration. Furthermore, the reflection process requires time, and people can gradually learn to be more reflective [LHS09, FF10].

Fleck and Fitzpatrick [FF10] presented five levels of reflection and techniques for supporting them. The lowest level of reflection is *description without explanation*. In this kind of reflection, collected information is presented to the user without further explanation. Revisiting such kind of collected personal information or knowledge is not treated as a reflective process. However, looking at this information can later lead to reflection. Technologies that enable to capture personal information and knowledge can support this level of reflection. Lifelogging devices or digital journaling tools are examples of such technologies. The second level of reflection is *reflective description*. In this kind of reflection, revisited information is accompanied by an explanation. The reflective description can be supported by annotation technologies or reflective questions. Such questions can encourage people to think about previous knowledge, events or information. Notifications on mobile devices can be used to ask reflective questions and hence trigger reflection. The next level of reflection is *dialogic reflection*. The dialogic reflection includes a questioning of information or knowledge and looking for alternative explanation and understanding of it. This kind of reflection can be supported by tools that assist users in revisiting the same information multiple times. Furthermore, using technologies that enable users to see the information from other points of view can also promote dialogic reflection. Lifelogging devices, for instance, can capture and visualize such kind of information (*e.g.* sleep behavior) that people cannot observe unaided. Furthermore, technologies that enable revisiting information multiple times can prompt reflection and reflector can gain an alternative explanation of it. In addition, technologies enabling sharing of information can encourage this level of reflection. By accessing the shared common information, a reflector can see it from other perspectives. *Transformative reflection* is a fourth level of reflection. This kind of reflection leads to an alternation of practice and understanding. After transformative reflection, people can change their point of view about the reviewed information. The final level of reflection, *critical reflection* occurs infrequently. This kind of reflection is accompanied by taking into account social and ethical consideration. The technologies supporting dialogic reflection can also be used to prompt the last two level of reflection. After a dialogic reflection, for instance, users can see revisited information from another point of view, and this can lead to alteration in the understanding of the information.

In related work, reflection is mostly discussed in the fields of education, design and healthcare. The following chapters present some related work that shows the benefit of using reflection on these fields.

2.3.1 Reflection in Education

As we discussed in the previous chapter, different levels of reflection leads to learning new things or seeing the previous information and knowledge from a new perspective. These properties of reflection make it valuable in education. Furthermore, Collins and Brown [CB88] suggest that learning process can be enhanced, if students have a possibility to evaluate their problem-solving attempts. If students reflect on their strategies used to solve the problems, the point of failures and successful outcomes, they can improve their process of learning.

Collins and Brown [CB88] suggest several techniques to support reflections in a learning process. These include *imitation*, *replay*, *abstracted replay* and *spatial reification*. In imitation technique, a teacher imitates students' actions, accenting their correct and incorrect actions. During imitation, the teacher can orally describe their actions. In the replay technique, the learning process of students is video recorded from different angles. Such a recording enables students to watch at and discuss their actions with the teacher. It is also advantageous that recorded learning process can be replayed as often as needed and paused in important places to discuss them with the teacher. Since the learning process is fully recorded, it can be difficult for students to observe the critical points unless the teacher points at them. This problem does not occur in the abstracted replay technique. In this technique, selected elements in the recorded learning process are highlighted. Such a highlighting facilitates students to pay attention to the critical features. Alternatively, in spatial reification technique, an unfolding of the learning process is statically represented over time. Such a representation makes it possible to easily track and analyze the learning process over time.

Tseng and Bryant [TB13] describe an interactive system, which enables children to create designs using tangible simple machine components. In this system, some reflection techniques are used that Collins and Brown described in their work, including abstracted replay and reification [CB88]. In addition to these techniques, juxtaposition technique is used in this work, too. In juxtaposition technique, users can enhance their learning process by comparing their work with another's. The interactive system provides episodic and summary interfaces for reflection. After solving a challenge and saving the design, episodic reflection interfaces, such as *Playback*, *Design Questions* and *Comparison* are offered to children. The reflection process is audio recorded and stored together with the design. In the Design Question interface, children are invited critically analyze their designs by questions. Children can look at the abstracted replay of their design process in the Playback interface. Furthermore, the reflection process is in this interface encouraged with questions. The Comparison interface enables children to juxtapose their designs against another's. After using the episodic reflective interfaces the summative interfaces, Piece Usage Overview and Portfolio, are provided to the children. Using the Piece Usage Overview a child can analyze the pieces that he used for the design and compare them with other user's usage of pieces. In the Portfolio interface, an abstracted reification for each of their designs is presented. It is observed that using the reflective interfaces encourages users to reflect on their work, and this leads to transformation in their understanding.

Beale [Bea07] found that students improve their learning when they write blogs about the topic that they recently learned. The authoring blogs encourage students to reflect on learning material. Furthermore, writing blogs can also encourage other students to reflect on the learning material. For example, reading opinions of a fellow student about recently learned material can assist students to reflect on this knowledge and gain new insights about the topic.

Lamberty and Kolodner [LK05] use camera talk technique to enable students to reflect on their work. In this technique, students are encouraged to speak directly to the camera in the classroom about their work. It was observed that students were particularly reflecting when they explained their previous knowledge about or solutions to the problems they were working on.

2.3.2 Reflection in Design

Reflection is also a valuable activity for the design process. Reflecting on the design process can enhance design ability and lead to better solutions [BKM$^+$14]. Schön [Sch83] defines two reflection activities: *reflection-in-action* and *reflection-on-action*. When considered in the context of designing, the former occurs while a designer is drawing a representation. Such a reflection can lead to making changes in the representation, such as changing a color or a size of a line. The latter reflection occurs after finishing the representation. Reflection-on-action does not lead to big changes in the design. It is a post-design cognitive process where the designer is reflecting on the representation or the design process.

We can deduce from the Schön's contribution in design theory that the reflection-in-action is an important component during the early stages of the design process [NYTR00]. It helps to make important improvements to the representation at the beginning of the design process. On the other hand, engaging in reflection-on-action, such as revisiting previous design processes and decisions helps designers better understand the design problems, easily handle the same design situations in the future and create new ideas from existing ones. Sharmin and Bailey [SB13] found that designers intentionally and often engage in reflection-on-action process and use design materials particularly as an aid for reflection. They presented ReflectionSpace - a visualization tool to support reflection-on-action. The tool enables users to map design materials onto suitable design process and context of use and create time- and activity-centric representation of them. Furthermore, ReflectionSpace facilitates designers to navigate through the resulting representations and examine them.

Reflection is a valuable activity while designers are working alone or in groups. Designers working in groups can reflect on each other's ideas, thereby generate new ideas or improve existing ones. Such a process increases the creativity of the individual and the group [HHL+07]. Involvement of users in the reflection processes can also bring improvements to the design process. A co-reflective session between designers and users facilitates designers to deeply understand the design space and comprehend behavior and desired functionalities [TFO09].

2.3.3 Reflection and Self-knowledge

Another benefit of reflection is providing self-knowledge. People are interested in self-reflection since ancient times. Ancient Greeks were greeted with the inscription "*Gnothi seauton*" or "*Know thyself*" when they pilgrimaged to the Temple of Apollo at Delphi to find answers [LDF10]. It is found that examining one's data has many benefits, such as encouraging positive behaviors, enhancing self-control and facilitating recall of past events [BKM+14, LDF11]. Furthermore, reflecting on positive events enhances well-being by improving mood and increasing self-esteem [IKW+13]. However, reflection about negative events improves well-being, too [IKW+13, PC11]. It assists people to convert upsetting feeling about the negative events to positive experiences.

People can reflect on their data by collecting personal information, including their habits, behaviors and thoughts. Nevertheless, the recording personal information is a challenging task. It is not possible for us to observe our behaviors all the time, and it is difficult for us to find patterns in our behaviors [LFD10]. Therefore, *personal informatics systems* are used. Personal informatics systems are tools that support people to capture their personal information, analyze it to find patterns and visualize it for the purpose of reflection.

People use different tools for collecting information about themselves, such as pen and paper, websites, applications and quantified self devices. The information can be captured manually, like writing a diary entry, or automatically using lifelogging devices. The recorded information can be quantitative (*e.g.* hours spent on sleep) or qualitative (*e.g.* information about user's mood).

Li *et al.* describe stage-based model of personal informatics [LDF10]. The model consists of five stages: *Preparation*, *Collection*, *Integration*, *Reflection*, and *Action*. The tools that facilitate users in their personal informatics activity must provide these stages [LDF11]. In the Preparation stage, people decide the information that will be collected. Furthermore, they determine how that information will be recorded. During the Collection stage, different personal information is recorded. People must decide in which frequencies information will be recorded. The Integration stage concerns with the preparation of collected data for the reflection which occurs in the Reflection stage. The Action stage occurs after users reflect on their collected personal information. In this stage, users see their actual status and compare it with their goals. It may encourage them to change their behavior to achieve their goals or to get a new understanding of themselves. The presented stages are dependent on each other. The problems occurring in early stages can affect the later ones.

During reflection on personal information, people are interested in questions about the status, history, goals, discrepancies, context and factors of their data [LDF11]. Some people reflect on their data to check their current status. Being aware of their current status can help them find out whether they meet their goal. People are also interested in examining their data over a period of time to find patterns and trends. Besides knowing their current status and history, people are also interested in defining their goals. People can use self-tracking devices to know their status and determine goals on the basis of this information. Once people know their current status and goal, they can make a comparison between them. Knowing the discrepancy between them, they can figure out how to change their behavior to reduce the discrepancy. People are also interested in finding the impact of other occurrences on them that are happening at the same time as their current information-seeking context. Factors that influence their behavior over a long period of time are also interesting for people. By knowing all factors affecting the particular behavior, people can react to them to improve that behavior.

Collection and reflection are the parts of personal informatics. Personal information must be available to reflect on it. Different tools are used to capture personal information. Lifelogging research concerns with the using of various sensors to record the daily life of people. Devices supporting lifelogging primarily track users' activity data, including exercising, sleeping and eating. Gemmell *et al.* [GBL06] describe *MyLifeBits* - a platform that stores different type of personal information, such as communication activities, web-browsing activities, calendar events and locations. *SenseCam* is a wearable device that automatically captures images [HWB+06]. The device is aided by sensors to automatically trigger the capture. For example, sudden change of light or temperature can trigger the camera to take pictures. Furthermore, pictures can also be taken in fixed time interval or manually by a user. Pictures taken by SenseCam can be used as a memory aid. Reviewing captured pictures by this wearable camera assists people to recall events of the previous days [HWB+06].

Reflection also has several benefits for physical and psychological health. UbiFit is a system that enables users to self-monitor their physical activity [CKM+08]. The user study with this system showed that users with the UbiFit system can retain their physical activity level over time. However, during the study, the physical activity level of the users without UbiFit decreased. Frost and Smith [FS03] describe how encouraging diabetics to take pictures of their food consumption, physical activity and stress management habits can give them a further clue to understand the reason of their blood sugar level. Reflecting on both those photographs and glucose data recorded on the same day facilitates diabetics to understand their condition and find out what behavior must be changed to have a normal blood sugar level. Isaacs *et al.* present *Echo*, a smartphone application that enables recording daily experiences and reflecting on them [IKW+13]. Using this application, users create new recordings by writing a subject line and rating their current happiness. Optionally, users can add a description, images, videos and audio recordings. Users reflect on the recordings by looking at the initial entry and all subsequent reflections of it. After reflecting, the user can edit the entry, and current happiness about this entry must be re-rated. Echo application reminds users to reflect on recordings using the Android's notification feature. Evaluation of this application showed that recording and reflection on personal data improve well-being.

There are various commercial products that facilitate people to record personal information and reflect on it. *Narrative Clip* [1] is a wearable camera that automatically captures photos. The device can take pictures in a 30 seconds interval or manually triggered by double tap on it. The Narrative smartphone application makes it possible to navigate through taken pictures and to reflect on them. There are several commercial wearable fitness trackers, such as *Fitbit* [2] and *Jawbone* [3], that enable people to keep track of their movement and sleep behavior. Furthermore, some fitness trackers can mess the heart rate and calories burned during a day. Most of the fitness trackers do not have any display. However, they have smartphone applications that visualize the tracked data for reflection. Smartphone applications, such as *RunKeeper* [4] or *Endomondo* [5] use sensors of users' mobile phone to track and display their fitness activities. *1 Second Everyday* [6] is a mobile phone application that assists users to record a one second video of each day and assign it to a calendar. The application can then combine all these videos to create a movie of the user's life. Watching that video can help users to recall previous days.

2.3.4 Downside of Reflection and Privacy Issues

In the previous chapters, we discussed the benefits of reflection in different fields, including education, design and self-awareness. However, in some cases, reflection can have downsides. Human memory fades over time [BKM+14]. Furthermore, people tend to forget negative experiences faster than positive ones [IKW+13]. Nonetheless, tools using reflection to enhance recall can lead users to remember negative events that they do not want to remember anymore.

Tools that support reflection use various types of private information. These tools should preserve users' privacy. Stakova *et al.* [SSS+15] suggest methods to preserve privacy while personal data are collected for the purpose of research. Personal data must be stored locally and securely. Furthermore, the data should be analyzed locally, and anonymized result of the analysis can be transferred to the researcher only via an encrypted connection.

[1] http://getnarrative.com, last visited on March 30, 2016
[2] http://www.fitbit.com, last visited on March 30, 2016
[3] https://jawbone.com, last visited on March 30, 2016
[4] https://runkeeper.com, last visited on March 30, 2016
[5] https://www.endomondo.com/, last visited on March 30, 2016
[6] http://www.1secondeveryday.com/, last visited on March 30, 2016

3 Concept

The aim of this work is to investigate the impact of reflection on recall of implicitly recorded personal information and to find out what kind of implicitly collected data is valuable as a memory cue. Collecting personal related data implicitly has several benefits. First, it does not interrupt users from their daily life. The users do not have to make pauses between their daily activities to record the data. Second, users do not need to spend extra time and pay attention to all occurrences for the data collection since it happens automatically. Third, a lot of information can be recorded during the implicit data capturing, even those that can be ignored by the users. By manually capturing personal related information, it can be difficult for users to decide which information is important to record. Furthermore, it is difficult or impossible for persons to observe all their behaviors. For example, sleep behavior cannot completely be monitored without help. Moreover, some information may be left unrecorded because of a lack of time or motivation. Finally, manually recorded information can be inaccurate. A user may not have enough time to record an event while it is occurring and later record of this event may contain imprecise information.

Memory cues are information that assists persons to recall associated events or knowledge. Tulving [Tul84] suggests that retrieval of the episodic memory system occurs as a process of a synergistic combination of information in the episodic memory and information provided as a memory cue. In the same work, Tulving proposes the retrieval query for the information in the episodic memory system as follows: "*What did you do at time T in place P?*" Using this query we can deduce that information about the occurrences, persons, time and location can be used as an efficient memory cue. On top of that, we can categorize this information accordingly as *What*, *Who*, *When* and *Where* memory cues.

In order to evaluate the impact of reflection on implicitly collected information on the recall, we propose *ReflectiveDiary* - an Android application that automatically records user's data and prepares it for reflection. Furthermore, the application can use the collected data to quiz users.

3.1 ReflectiveDiary

ReflectiveDiary is an Android application that supports users to reflect on implicitly collected information about them. Its features enable automatic collection of several personal information using various sources. Since the collected data consist of personal related information, it is only stored locally on the users' device. ReflectiveDiary not only collects that information but also encourages users to reflect on it. The application uses, for this purpose, the Android's

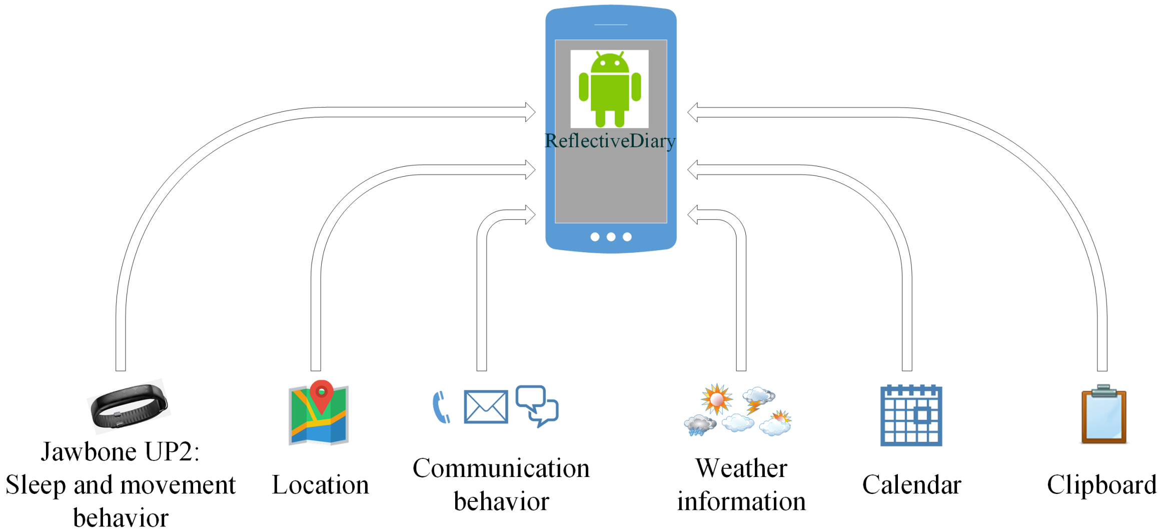

Figure 3.1: Collected information in ReflectiveDiary application. The application automatically collects information about user's communication, sleep and movement behavior, visited locations and weather information in those locations, calendar events and smartphone clipboard information.

notification feature and prompts users to reflect on the data collected on the previous day. To reflect, users view the entries belonging to the previous day. Furthermore, the application enables users to rate their happiness about the current day. Another feature of the application makes it possible users to quiz their knowledge about the collected data on previous days. The generated quiz questions are based on already recorded user's information. The following sections describe the concept of the Android application in detail.

3.1.1 Data Collection

The application uses various sources for the data collection. Figure 3.1 shows data that the application implicitly collects. They are the information about user's sleep and movement behavior, visited places and weather information for these places, communication data, calendar events and smartphone clipboard data. Furthermore, the application explicitly collects information about users' happiness rating.

The application collects users' communication data by observing the notification bar of an Android smartphone. All received SMS messages and messages from the social network, messaging and email client applications are collected. Furthermore, the application collects information about incoming and outgoing phone calls. This information contains several important memory cues. By using the categorization of memory cues defined in chapter 3, user's recorded communication data contains *Who*, *What* and *When* memory cues. First, it contains information about persons that the user communicated with. Second, the content of messages may include important information to remember the day that the messages have been received. Finally, the date and time of phone calls and notifications from messaging, social network and email client applications can be used as a memory cue.

Another information type collected is users' visited places. Location information can help users to reconstruct personal memories, even if they do not exactly recall them [KSWK10]. The ReflectiveDiary application tracks the location of users and records it if the location is significantly different from the previously recorded one. The collected location data contains both *Where* and *When* memory cues. Each time the application collects location data, the current date and time are recorded as well. Moreover, weather information of the users' current location is also collected, if it is considerably different from the previously recorded one. The recorded weather data contains information about weather changes. This occurrence represents *What* memory cue. Furthermore, time of this occurrence indicates *When* memory cue.

The other two information types collected directly from the users' smartphone are calendar data and clipboard information. The application periodically checks for the new calendar events stored on the mobile phone and copied text to collect. Calendar data can contain valuable information that can help users to distinguish a day from others. The information is either an event or a reminder. The calendar events, if completely entered, include *Who*, *What*, *Where* and *When* memory cues. They are accordingly information about attendee, title and description, location and finally the date of an event.

Clipboard information of a smartphone can also contain valuable information for users to assist recall. For example, a user can copy a text and save it to look at later or a user may be interested in a word and then copy and paste it into a web browser address bar to search for further information. The application records clipboard data together with the timestamp that the text was copied. Therefore, clipboard information contains *What* and *When* memory cues.

Users' sleep and movement information are used in the application too. This personal related information is ascertained using *Jawbone UP2* fitness tracker. The Jawbone UP2 armband is a wearable device and capable of automatically tracking user's sleep and activity data. It is difficult for a user to remember the exact number of steps taken in a day or hours slept each night. However, a user can define the movement and sleep goals and trace them using a fitness tracker. Using the information about the achievement of sleep or movement goal together with other memory cues recorded on the same day can help users to recall that day. Since sleep and movement data do not contain information about persons and places, they belong to *What* memory cue. Furthermore, information about a recorded date indicates *When* memory cue.

It is found that recording events and reflecting on them benefit psychological well-being [IKW+13]. That can be explained with the "Rosy View" phenomenon [MTPC97]. It argues that the negative aspects of an event, which seem to be caused by distraction, frustration and a less positive view of the self, are transient, and within a few days after the occurrence of the event people subconsciously edit these negative aspects. Furthermore, it is shown that emotional arousal improves the recall of the memory associated with the emotionally arousing event [SFR+13]. Therefore, the application collects users' happiness

Entry type \ Memory cue	Who	Where	When	What
Calendar	+	+	+	+
Call	+		+	
Clipboard			+	+
Location		+	+	
Movement			+	+
Notification	+		+	+
Sleep			+	+
Weather			+	+

Table 3.1: Entry types of the ReflectiveDiary application and their providing memory cue categories. The entries of the application provide information about persons, locations, time and other contextual information (*e.g.* weather information, the title of a calendar event). This information can be used as a memory cue, and they are categorized to *Who*, *Where*, *When* and *What* memory cues.

rating to find out the impact of well-being on recall of implicitly collected data. In contrast to the data as mentioned earlier, happiness rating is recorded explicitly.

The implicitly collected data are entries of ReflectiveDiary. To distinguish these entries from each other we defined 8 entry types. They are *Calendar*, *Call*, *Clipboard*, *Location*, *Movement*, *Notification*, *Sleep* and *Weather* entry types. These entry types and their providing memory cues are shown on the table 3.1.

3.1.2 Data Presentation

After collecting various personal information, it must be presented to the user to prompt reflection. The ReflectiveDiary application not only presents the gathered information but also supports users to reflect on it. Different visualization methods can be used to present the data. Prior work [Con09] proposes that episodic memory preserves the temporal order of the occurrence of events. Since the application collects each data together with their occurrence timestamp, the recorded information is represented in the temporal order. Furthermore, each information type is shown with its occurrence date and time.

Each communication data is displayed with an icon, the name of a person and a text. The icon shows the person who called or wrote a message. If there is not any picture available for the person on the smartphone, the default icon of the corresponding application will be displayed. The text contains either the content of the message received or information about callee or caller. Figure 3.2 (a) shows an example for the presentation of recorded communication data. It is a received message and displays the content of it, the name and the icon of the sender and date that the message was received.

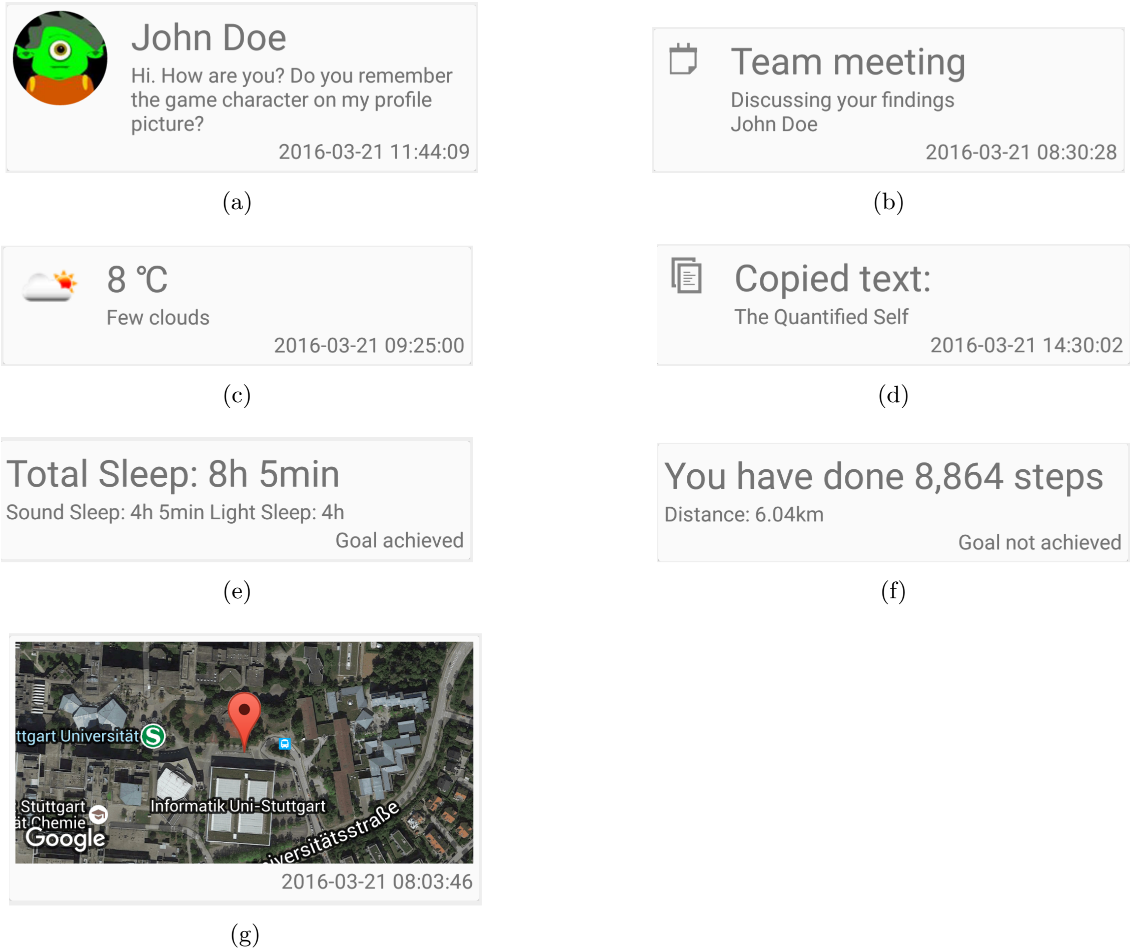

Figure 3.2: Presentation of the collected data. (a) An example for the presentation of received messages. It consists of a received message, an icon and the name of the sender, and received date. (b) An example of the calendar event. It is represented by the name, description, list of participants and the date of the event. (c) An example for the presentation of weather data at a certain location and time. (d) A presentation illustrates clipboard data with a copied text. (e) A presentation of sleep data. It displays total sleep duration a night and duration of sound and light sleep. Furthermore, it shows if the sleep goal of a user is achieved. (f) A movement data is displayed by a number of steps taken within a day and distance walked or run. It also shows if the user achieved his daily movement goal. (g) An example for displaying location data. The current location of a user according to the displayed date is marked on the map.

Location information is displayed as a map with a marker showing the position of the user. There are several works suggesting visualization of the location data. Venkatanathan *et al.* [VFB+11] propose trajectory reminders for this purpose. The trajectory reminders are user interface indicating user's particular location together with the locations visited before and after. It is found that presenting location data with trajectory reminders assists users to reconstruct the experience of the location visit [VFB+11]. The ReflectiveDiary application tracks the location of users every 20 minutes. If the current location of a user is significantly different from the last recorded one, it will be recorded by the application. Although the application does not show trajectories, representing a user's visited places in a list resembles trajectory reminders. In ReflectiveDiary, users can scroll a list of entries and view all location data collected within a day. Figure 3.2 (b) illustrates the presentation of location data.

Figure 3.2 (c), (d) and (e) shows how the ReflectiveDiary application displays respectively weather data, calendar events and clipboard data. A weather description, corresponding weather icon and temperature are shown to represent weather information. Calendar data is represented by the calendar icon, title and beginning time of the event. Moreover, event description and a list of participants are also displayed, if they are available. The clipboard data is displayed by an icon and the copied text.

In figure 3.2 (f) and (g), representation of sleep and movement data are shown. To illustrate sleep behavior of a user total sleep duration, the duration of light and sound sleep and if the user's sleep goal achieved are represented. Similarly, the number of taken steps and achievement of daily movement goal are shown to present user's movement behavior.

3.1.3 Quiz

The application also provides users the opportunity to quiz themselves about the collected data. ReflectiveDiary automatically generates questions for quizzes using already recorded information. On that account, enough data must be contained in the application database. Each quiz consists of several questions, and every question is accompanied by a hint. Both questioned and hint are created from two entries collected by the application. These entries have different entry types. Using two distinct entries to generate questions and hints enables us to find out what entry type can be used as an efficient memory cue to support the recall of other entry types.

3.2 Architecture

Figure 3.3 illustrates the basic architecture of the prototype containing ReflectiveDiary application and a server. The ReflectiveDiary application has two databases. One of them contains users' private information. Collected various information types are stored in this database. The other database, on the other hand, is a storage of data that are necessary for the evaluation of the prototype. This database contains abstract information about data collected by the application. Furthermore, information about taken quizzes is also stored in that database. The content of this database is synchronized with the data stored in the remote database on the

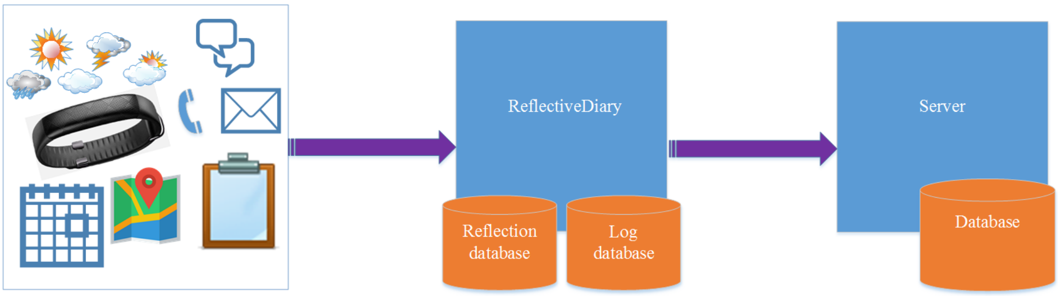

Figure 3.3: The basic architecture of the prototype. The ReflectiveDiary application collects various information from different sources and stores them in the reflection database. The log database serves for locally storing the data for the evaluation. The information in this database does not contain any private information. Log database is synchronized with the remote database on the server.

server. Both databases of the Android application are separated to preserve the user's privacy. The private information is locally stored and does not leave the users' device. Information stored in the database for logging purposes is anonymized. It is not possible to backtrack the user using this data. As soon as the Internet connection is available on users' device, and there are new entries in that database, the application uploads these entries to the database on the server. The remote database is designed for the later evaluation of the concept.

4 Implementation

This chapter describes the implementation of the Android application and the server mentioned in chapter 3. First, we discuss the implementation of the Android application. At the same time, the features of the application - data collection, data presentation and quiz are presented. We then describe the server that deals with a database to store the data for the evaluation.

4.1 Android Application

The Android application (ReflectiveDiary) works with the devices running Android 4.4.2 and later. The application collects implicitly personal related data and prompts users to reflect on them. Furthermore, the application enables users to record their happiness rating. On top of that, the application allows users to test their knowledge about recorded data on previous days. For this purpose, ReflectiveDiary automatically generates quizzes using the collected data.

ReflectiveDiary contains two databases. One database stores all collected private information about a user. This information is only stored locally on user's device. The other one deals with data that is necessary for the evaluation of the prototype. This database does not contain any private information and is synchronized with the database on the server. The following chapters present the implementation of features of the Android application.

4.1.1 Initial Setup

In order that the application properly works, several setups must be done. ReflectiveDiary collects received messages using the information on the notification bar of users' smartphone. In order that the application can retrieve that information, access to notifications has to be enabled. It is not possible to observe notifications only using the Android permissions. Users have to grant explicitly an application to access notifications. Therefore, on its first run, the application opens Android's notification access settings and asks users to grant the application to access the notifications. The users must enable the checkbox in the system settings to confirm the access and then return to the application. Furthermore, in order to permit the application to collect user's visited places, location access has to be enabled as well.

The application can also record user's movement and sleep data through wearable fitness tracker. For this purpose, ReflectiveDiary accesses the UP API of the Jawbone. In order that the application requests these data using the API, users have to log in to Jawbone. For this purpose, the application provides an authentication method. Using the button on the main view of the application a user can open the login page of Jawbone (see Figure 4.1). After

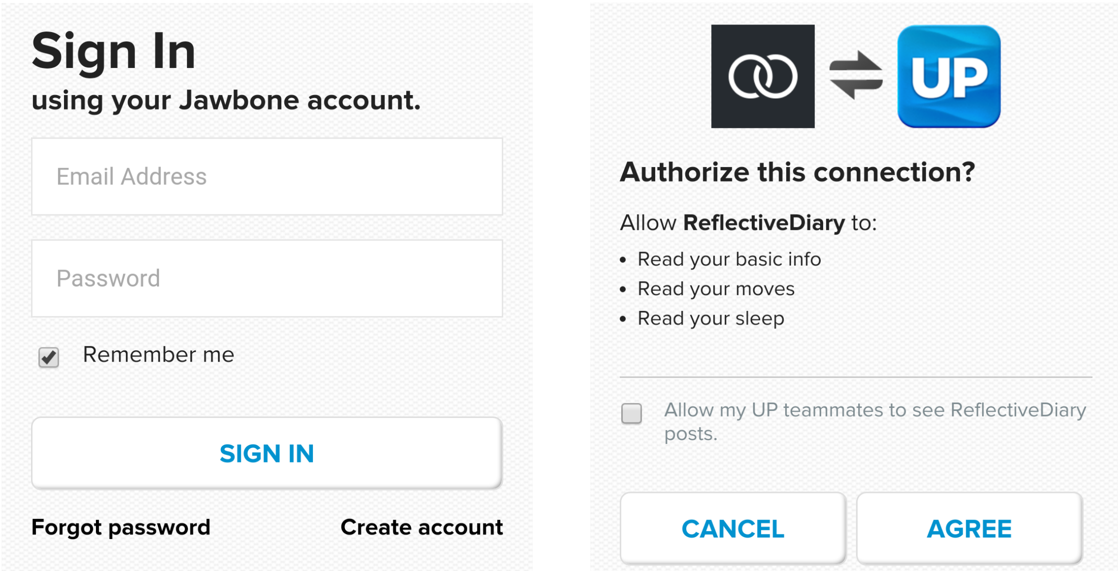

Figure 4.1: Login page of Jawbone. ReflectiveDiary collects movement and sleep data through Jawbone UP2 fitness tracker. For this purpose, users have to log in to Jawbone and permit the application to access their sleep and movement data.

entering the login credentials and confirming them, a list of permissions is displayed to users that the application requires for the access to movement and sleep data. After acknowledgment of the permissions, the application returns to the main view. The application then requests for an access token of the API and then stores it for the later API calls. The main view of the application consists of a button for the Jawbone authentication and instructions about the setup.

On its first run, the application generates a hash code which indicates the user ID. This ID is unique for every user and stays the same while using the application. The application then sends the ID to the server to register the user. The server then generates a unique authentication code, stores it in its database and sends it back to the application. Further requests are only granted by the server if the authentication code is attached to them.

4.1.2 Data Collection

The Android application uses several sources for data collection. It implicitly records user's communication, calendar events, sleep and activity data, visited places and weather information for these locations, and copied texts on users' smartphone. All these data are recorded between 7 a.m. and 11:59 p.m. and stored only on the user's device. Table 4.1 shows APIs that the application uses to collect data. Furthermore, it presents the time intervals in which ReflectiveDiary accesses these APIs. In following sections, we discuss the implementation of data collection features of the application.

Entry type	Used API	Access interval
Calendar	Android Calendar Provider API	once a day
Call	Android TelephonyManager API	permanently
Clipboard	Android ClipboardManager API	permanently
Location	Google Play Services Location APIs	every 20 minutes
Movement	Jawbone UP API	once a day
Notification	Android NotificationListenerService API	permanently
Sleep	Jawbone UP API	once a day
Weather	OpenWeatherMap API	every 2 hours

Table 4.1: Used APIs and time intervals for the data collection. The application collects data using APIs provided by Android, OpenWeatherMap API and Jawbone UP API. These APIs are accessed in different time intervals.

Communication Data

As a communication data ReflectiveDiary collects incoming and outgoing phone calls, received SMS messages and messages from the social network, messaging and email client applications. On its first run, the application registers an Android BroadcastReceiver to listen to phone calls. Once there is a phone call, the application is notified about it. The application then retrieves incoming or outgoing phone number and searches contact information on the mobile phone belonging to that number. If contact information is available on the device, the name and photo of the contact owner are retrieved and stored in the application's database. If that is not the case, the application records this phone call with its number and the default icon.

Incoming SMS messages and messages from the social network, messaging and email client applications are collected through received Android notifications. Figure 4.2 shows the structure of Android notification. It consists of an icon, a title, a content and receiving time of the notification. In most of messaging, social network and email client applications, the title of notification indicates sender name and received message is shown on the content of a notification. By using NotificationListenerService provided by Android framework we can access elements of Android notification. Furthermore, it is possible to retrieve the application that has fired the notification. Since ReflectiveDiary collects only notifications fired by messaging, social network and email client applications, it filters notifications by applications and ignores those that do not belong to above-mentioned applications. For this purpose, we stored package names of popular those kinds of Android applications in a list in the application. Once the smartphone receives a new notification, ReflectiveDiary retrieves the package name of the application

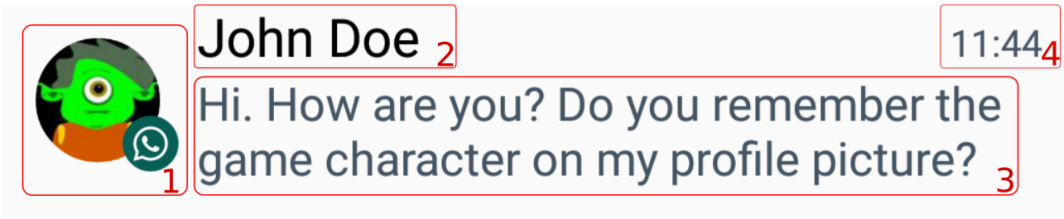

Figure 4.2: Structure of the Android notification. Each Android notification contains (1) an icon, (2) a title, (3) a content and (4) time indicating when the notification has been received.

owning the notification and checks if it is on the list. If it is the case, the application will record the title, content, icon and fired time of the notification. The package name of the firing application will be stored as well.

Location Data

ReflectiveDiary collects user's location data using Google Play Services Location APIs. On its first run, the application checks the availability of Google Play Services on the smartphone. Once they are available, the application connects to location services provided by Google Play Services and periodically requests location updates. ReflectiveDiary tracks user's location every 20 minutes and records it if the current location is at least 100 meter different from previously collected one. Thus, being viewed on a map, those recorded locations are distinguishable by the user.

Calendar Data

Every day, ReflectiveDiary looks for calendar events stored on the device that belongs to the previous day. We used Android's Alarm Manager feature to schedule the application to collect calendar data periodically. Once a day, approximately at 3 p.m., the application lists all calendars that are synchronized with the Android device and collects events stored on them. All calendar events have at least a name and begin and end time. If description and participant of the events are available, ReflectiveDiary will record them too.

Clipboard Data

If a user copies a text using an Android smartphone, it will be put into a clipboard object and stored in the Android's clipboard feature. In order to collect copied texts, ReflectiveDiary, on its first run, starts a service that listens for mobile phone clipboard changes. If there are any changes in the clipboard, the application will verify the metadata of the current clipboard object in the clipboard. Once the clipboard data contain a text, it will be stored in the application's database.

Weather Information

ReflectiveDiary collects weather data by accessing OpenWeatherMap API [1]. Every two hours, the application monitors the availability of Internet connection of the device. If it is available, ReflectiveDiary queries last recorded location of the user and accesses the API to retrieve current weather information for this place. The accessed weather data is recorded on the application database if it has a different weather description than that of the previously stored one. The retrieved weather data is also stored if the temperature of it is at least 3° C different from that of the previously recorded one.

Movement and Sleep Data

User's movement and sleep data are recorded through the UP API of Jawbone. In order to access this API we used UP SDK for Android [2]. This SDK provides authorization methods for Jawbone and interfaces for making requests to REST endpoints of the UP platform. Once a day the application requests movement and sleep data of a user that were tracked the previous day. Before making the request, ReflectiveDiary checks the availability of the Internet connection of the device. If it is not available, the request will be postponed for two hours. If the smartphones' Internet connection is present, the application requests goals for sleep and movement that the user has manually set using the Android application of Jawbone. Afterward, the user's sleep and movement information are retrieved. Since sleep and movement goals can be anytime modified by users, they are requested each time when the application makes API calls to retrieve sleep and movement data. Recorded movement and sleep data are separately stored in the database with the information about the achievement of daily goals.

4.1.3 Data Presentation

ReflectiveDiary can prompt users to reflect on their collected data. To reflect users view the entries belonging to the previous day recorded by the application. For this purpose the application queries all entries of the previous day and shows them in an Android RecyclerView. All entries except movement and sleep information are illustrated in occurrence order. Sleep information is shown as the first and movement data as the last element of the list. After viewing all entries on the list users are prompted to rate their current happiness (see Figure 4.3). The happiness scale is illustrated with 9 radio buttons. Once a user selects one of them, an emoticon is displayed that shows the corresponding happiness rating.

[1] http://openweathermap.org/api, last visited on March 30, 2016
[2] https://github.com/Jawbone/UPPlatform_Android_SDK, last visited on March 30, 2016

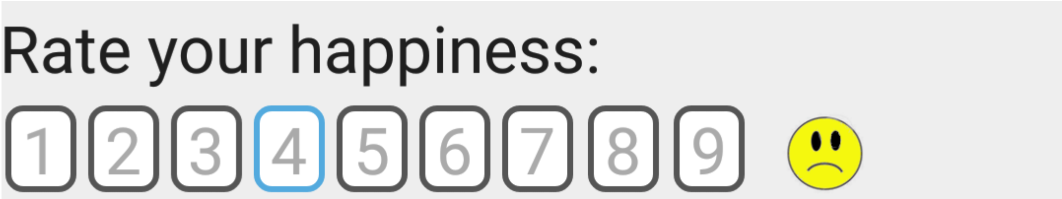

Figure 4.3: Happiness rating. Users can rate their happiness using the scale from 1 (low) to 9 (high). Each rating is accompanied by an emoticon.

4.1.4 Quiz

The Android application enables users to quiz their knowledge about the collected entries. For this purpose, the application queries entries stored in the database and prepares a quiz. Each quiz has several questions. The number of questions is dependent on the quantity of the data recorded a day. Each question is accompanied by a hint. Both question and hint are collected entries from two different types. The application can generate four different kinds of question: *who*, *where*, *when* and *what* questions. In *who* questions a person is asked. This kind of question can be generated if the quizzed entry is either a communication data or a calendar event. For example, caller or participants of an event can be quizzed in who questions. *Where* type of question can be asked if the questioned entry is a location data. In this kind of questions, the location of the user at a certain time is asked. The occurrence time of an event in entries is asked in *when* questions. This question type can be created for all collected information except sleep and movement data. In *what* questions, the content of the received messages, the copied texts and name of the calendar events can be quizzed. Furthermore, the application asks questions about occurrences like weather changes and achievement of sleep and movement goals in this type of questions.

The application provides four choices for each question except the type of the quizzed entry is movement or sleep. In these cases, achievement of sleep or movement goals at certain day is asked. There are two choices (*i.e.* yes and no) for the questions about sleep and movement. In *where* type of questions, the choices are displayed as maps with a marker indicating a possible location of the user at the certain time. Choices in a form of text are generated for the rest of question types. The choices are created using the data collected by the application. The application uses several rules for creating choices. First, all choices have to be distinct. In *where* questions, distances among locations marked on maps have to be at least 100 m. If there are not enough recorded location data to quiz user's visited places, the application will generate random locations that are not far from the user's already collected locations. Second, the choices have to be created using the data of the same entry type. For example, choices for a question like "What did John Doe write you using WhatsApp at 15:30?" are created from the collected WhatsApp messages that the user is received. All choices but one are either not from the same sender or recorded on the different day than the question refers to. ReflectiveDiary creates choices using the entries collected from the same source. However, if there is not enough recorded data, choices will be generated using alternative sources. For instance, if

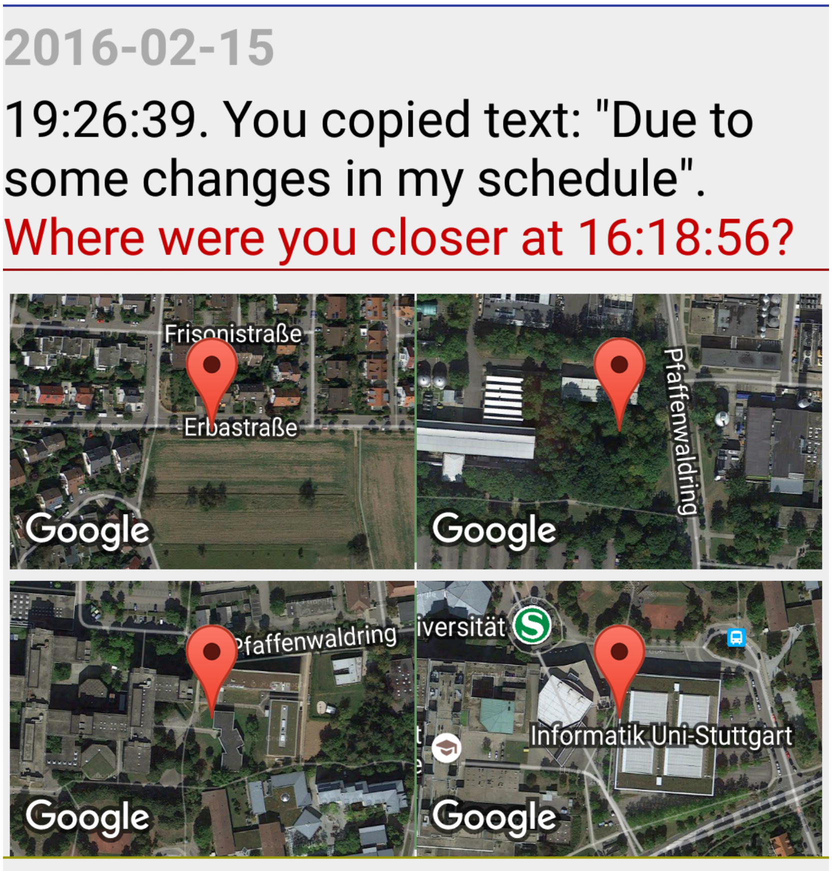

Figure 4.4: An example for a quiz. A clipboard information is used as a hint. The questioned entry is the location data. The user answers the question by tapping on one of the maps.

there are not enough recorded WhatsApp messages, the application can create choices using SMS messages or messages collected from other messaging applications. Figure 4.4 illustrates example for quiz generated by the application.

4.1.5 Databases

ReflectiveDiary uses two Android SQLite databases to store the collected information and application usage data. One database stores all information discussed in section 4.1.2. To distinguish these entries the application stores them together with their entry type. Since these data contain private information about the user, they are stored locally on the user's device. The second database, on the other hand, stores abstract information about the collected data and taken quizzes. This database has two tables: *reflection* and *quiz*. Each time when the application records a new entry, type of it and recorded time is stored in the reflection table. On the other hand, each entry of the other database table corresponds to a quiz question. The entries of this table contain information about the taken quizzes, including types of entries used as a hint and question, question type, date when these entries are created and correctness of user's answer. The entries of this database are synchronized with the remote database on the server.

4.2 Server

The server deals with the database that stores the application usage data for the evaluation. Its components consist of MySQL database and PHP scripts. The MySQL database has three tables. One contains user information, and the other two tables store users' quiz data and information about collected entries by ReflectiveDiary application. On the first run of the application, user information, such as a unique user ID and mobile phone information are sent to the server and stored in the database. Furthermore, every three hours the application checks the availability of smartphone's Internet connection and new entries in the database that stores usage data of the application. If they are available, entries are encoded in the JavaScript Object Notation (JSON) and sent to the server. A PHP script on the server handles the request and stores the data in the MySQL database.

4.3 Limitations

The application requires an active Internet connection to work properly. If Internet connection is not available on a user's mobile phone, the application cannot record sleep, movement and weather information. Furthermore, in that case, the devices do not receive notifications from messaging, social network and email client applications. Therefore, without an active Internet connection several communication data can be left unrecorded. On top of that, maps showing the location of users require an Internet connection to be displayed.

Ongoing notifications are a special case of Android notifications. These notifications are fired by applications to indicate long-running events and progress of these events. To show the progress of events ongoing notifications are frequently updated. For example, in communication applications, notifications are updated every second to indicate the duration of a phone call. When there is an ongoing notification of a messaging application, ReflectiveDiary records only the first notification and the rest notifications belonging to the same phone call are ignored.

In order that ReflectiveDiary records users' visited places, location access on their mobile phones have to be enabled. Letting the application periodically access to the current location of the users causes the battery of smartphones drain quickly.

5 Evaluation

To evaluate the impact of reflection on implicitly collected information on recall we conducted a study. The participants of the study installed the Android application described in the section 3.1 on their smartphones and used it for 17 days. The following sections discuss the conducted study in detail.

5.1 Design and Apparatus

To examine the impact of reflection on recall, we conducted a study. For this purpose, we used repeated measures design with reflection as an independent variable. To carry out the study we updated the application and added several new features. First, in contrast to the early version, the updated application prompts users for reflection every two days. The reason was to compare recall of a day with and without reflection. We implemented two versions of ReflectiveDiary. In one of them, users are notified for the reflection starting from the first day of the study. The second version, on the other hand, invites users for the reflection starting from the second day of the study. Days when users do not reflect, the application reminds them to rate their current happiness. We used for this propose the happiness rating scale from 1 (low) to 9 (high) accompanied by emoticons that correspond to each rating (see Figure 5.1 (a)). In the reflection days, users reflected and assessed their happiness rating (see Figure 5.1 (b)). Second, we modified quiz part of the application too. After the update, users had to rate the helpfulness of a memory cue used as a hint to recall the entry representing the question. For this purpose, participants had to rate the statement “The hint was helpful to remember the quizzed information” on a Likert scale from 1 (strongly disagree) to 7 (strongly agree). This subjective rating enables us to find out which memory cues (*i.e.* entry types) can be used together to support recall more efficiently. Finally, the application enables users to reflect on the entries belonging to the day that was quizzed. After finishing the quiz of a day, ReflectiveDiary displays the list of the entries of the quizzed day. After reflection, users are encouraged to assess the efficiency of the each entry type used as a memory cue to recall that day. Figure 5.2 shows the Likert scales that we used for this assessment.

The aim of the application is not to collect all received notifications. As described in section 4.1.2, ReflectiveDiary filters the notifications and records only those, that are fired by messaging, email client or social network applications. Although notifications from popular those kinds of applications were already filtered by ReflectiveDiary, we implemented an Android application to examine whether a user uses such kind of application that is not in the filter list. This Android application lists applications installed on a device and fades out those that are already on the list of filtered applications.

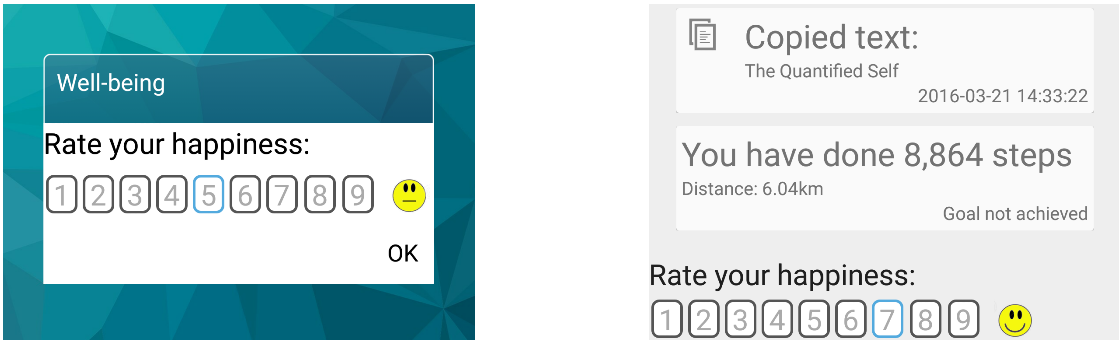

Figure 5.1: Rating of happiness. The rating scale accompanied by emoticons. (a) Happiness rating appears as a dialog window in non-reflection days. (b) In reflection days, users rate their happiness using the radio buttons appearing at the end of the list of reflected entries.

The study required an Android smartphone and a fitness tracker. The recruited participants used their own Android devices. All Android devices run at least Android version 4.4.2. To collect the sleep and movement data we used Jawbone UP2 fitness trackers (see Figure 5.3). This fitness wristband requires minimum interaction and can automatically detect and track the user's sleep and movement behavior. Furthermore, the battery life of the device is ten days which is enough for the recording session of the study. Thus, participants of the study can use the fitness tracker without needing to take it off for recharging. Since Jawbone UP2 needs to upload logged data to the Jawbone server, users have to install UP [1] application on their phone. Users need to pair the Jawbone UP2 with their Android device via Bluetooth to synchronize the collected data.

5.2 Participants

We recruited 11 participants via personal connections and university mailing lists, of which 2 were female. Their average age was 25.5 (SD=3.69) years. None of them owned any digital lifelogging device. 2 participants were keeping diaries, whereas 1 indicated using an Android application for this purpose. 4 participants stated to use to-do list applications and 1 used an application to track movement data.

[1] https://play.google.com/store/apps/details?id=com.jawbone.upopen, last visited on March 30, 2016

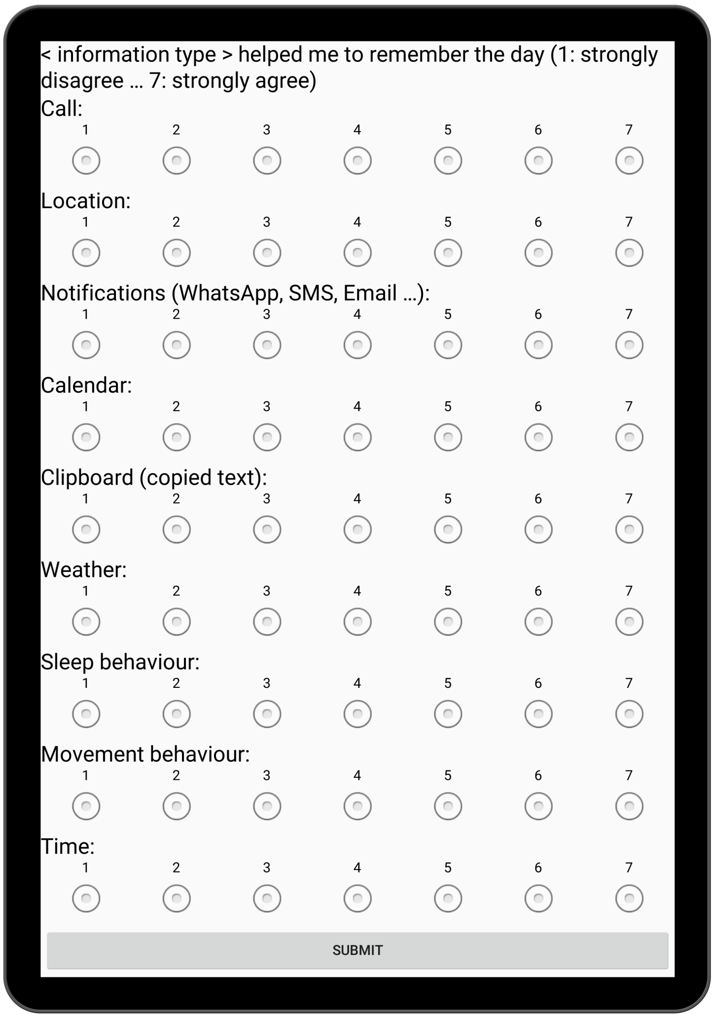

Figure 5.2: Likert scales used to assess memory cues. After each daily quiz, users reflected on all entries collected on the questioned day. Afterward, they were asked to rate how each memory cue was helpful to remember the day.

5.3 Procedure

After signing the consent form, we explained the purpose of the study to participants. We installed the application on their Android smartphone to view all installed messaging, email client and social network applications on the device. We made sure that ReflectiveDiary collected notifications of all of those applications used by participants. Each time when we found an application that was not in the filter list of ReflectiveDiary, we updated the list. Then, we asked participants to install UP application on their Android device and handed them a Jawbone UP2 fitness tracker. The participants then enabled the Bluetooth on their smartphone and paired it with the fitness tracker. After successfully pairing the devices we

Figure 5.3: Jawbone UP2 fitness tracker. This fitness wristband was used to track user's sleep and movement behavior during the study.

asked participants to create an account for Jawbone. Afterward, users set their goals for daily movement and sleep using the UP application. For some users, it was hard to set goals. We explained to them that they had to set initial goals, but they could anytime justify them. In the next step, we explained how to use the fitness tracker. Furthermore, we outlined users that each day of the study they had to synchronize the data collected by Jawbone UP2 with the UP application. After making sure that participants felt familiar with the device, we installed ReflectiveDiary application on their smartphone. Then, we asked participants to enable location and notification access for the application. Afterward, they logged in Jawbone using the login credentials that they created in the previous step. When the initial setup was ready, we showed participants screenshots of ReflectiveDiary to explain the features of the application.

The study consisted of two parts. All participants used the application for 17 days. In the first part of the study, which takes nine days, ReflectiveDairy collected personal related data and prompted participants either to reflect on recorded events from one day and rate their happiness about the current day or only assess their happiness rating about the actual day. Since collected data at the first day were not complete, we did not use it. Furthermore, data collection on that day were important for us to be sure that the application worked properly.

ReflectiveDiary prompts users to reflect on their previous day every two days. We tried to counterbalance the number of participants starting reflection from the first and the second day of the study. Every day approximately at 22 o'clock participants got Android notification that invited them to use the application. During this part of the study, we logged happiness ratings and types of the entries that were collected by the application.

After nine days we again met with the participants and explained the second part of the study. In the second part of the study, ReflectiveDiary application did not collect any personal related information. Thus, participants did not need to wear Jawbone UP2 anymore and returned it. Furthermore, they were free to disable location access on their Android device. The second part of the study lasted eight days. In this part of the study, participants were notified once a day to take a quiz. They got notifications for this purpose circa at 22 o'clock. Quiz questions were based on the information collected eight days ago. For example, on the tenth day of the study, quiz questions were about the entries collected on the second day of it. The aim of these quizzes was to examine the recall of the information collected by the application. After each question participants were asked to assess helplessness of used hint to recall the information used as a question. After taking a quiz participants reflected on entries of the recently quizzed day and were asked to rate every entry type used to present the day. In this part of the study, we logged quiz results and all subjective ratings.

After finishing the second part of the study we met with the participants and asked them to fill in a survey asking demographics. Afterward, we conducted a semi-structural interview with them. They were asked to recount memory cues that helped them a lot and less to recall their days, if reflection on their previous days affected their mood and if the application helped them to become aware of their phone usage and personal behaviors. Furthermore, they were encouraged to give examples of events that were recalled after reflection. Participants were also given the opportunity to provide improvements for the application and additional feedback.

6 Results

In this chapter we describe the results of the evaluation. For the evaluation, we performed both quantitative analyses of collected data in the remote database and a qualitative analysis of interview data. The following sections describe the results of the evaluation.

6.1 Quantitative Analyses

The application recorded a different number of entries for each participant, from 129 to 1679. Most of the entries were received notifications (80.8%). During the study 48 calendar events and 136 calls were recorded. The percentage of collected clipboard, location and weather entry types were 1.2%, 6.9% and 5.2% respectively. Since the quizzes were generated using the collected data, the number of questions in quizzes were also different. The number of questions answered by the participants varied from 40 to 110. The average happiness rating was 6.44 ($SD = 1.37$).

To find out whether reflection on implicitly collected data affects recall we collected scores of quiz results of every user. Since we used reflection as an independent variable, we could compare results of the quizzes generated using entries that users reflected and not reflected on (*reflected and non-reflected entries*). The average score of the quiz results generated using non-reflected and reflected entries were 34.561% and 51.379% respectively. We compared the quiz result using paired t-test. We observed that the difference between results of the quizzes generated using non-reflected and reflected entries are statistically significant $t(11) = -2.363$, $p < .042$.

In the first part of the study, participants rated every day their happiness score. Figure 6.1 shows the mean score of quiz results for each happiness rating. The rating scale was from 1 (low) to 9 (high). Rating scores 1 and 2 were selected just once, and rating score 3 was not selected by any participant. For further analysis we did not use these ratings. We examined a correlation between happiness rating and mean score of the quiz results. For this purpose, we ran a Pearson product-moment correlation. We found that the relationship between happiness rating and average score of quiz results was not statistically significant ($r = .203$, $n = 68$, $p < .097$).

After each quiz session participants rated information types collected by the application. We aggregated the ratings and created the boxplots illustrated in Figure 5.2. The boxplots show the agreement score to the statements "<information type> helped me to remember the day". The highest rating was received by *call* and *calendar* entry types, followed by *notification*, *time* and *location* entry types. To find out difference in agreement degree depending on information

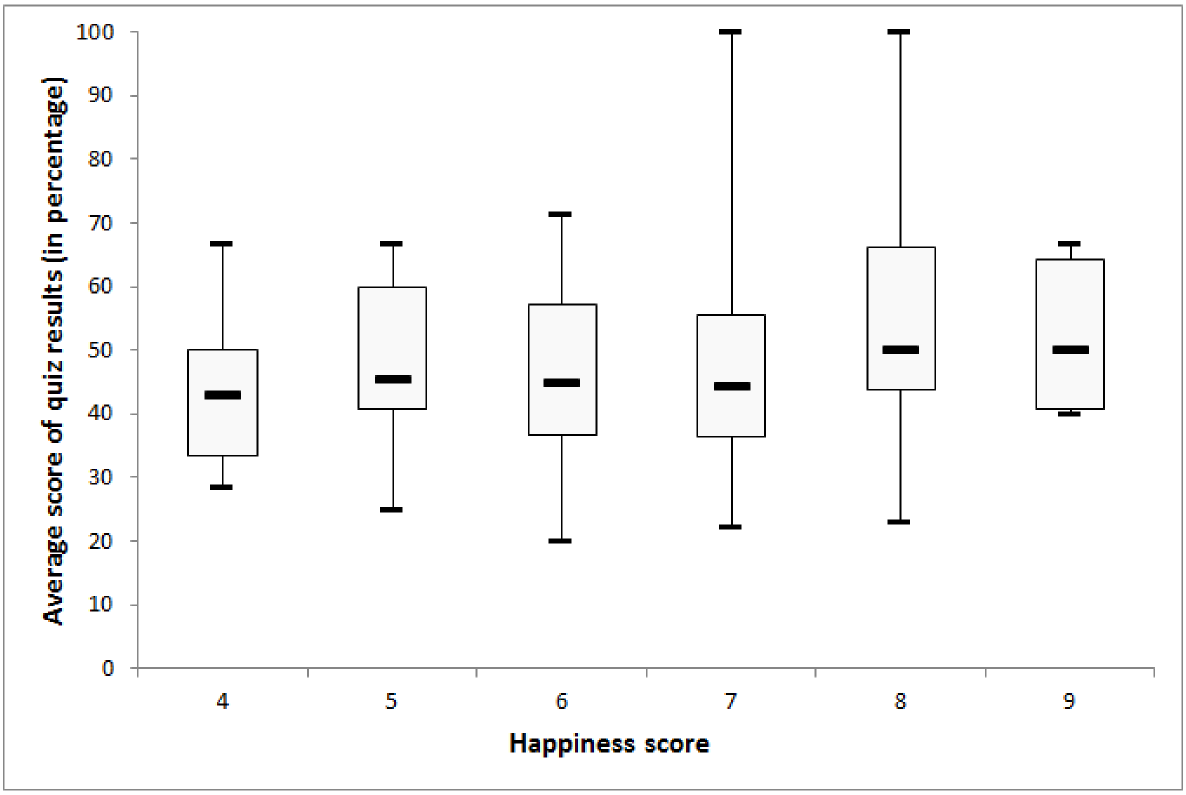

Figure 6.1: Average score of quiz results for each happiness rating. Only the happiness scores that at least 4 times selected are represented in this box plot.

types collected by the application we ran a Friedman test. The difference was statistically significant, $\chi^2(2) = 17.183$, $p = 0.028$. We conducted a post hoc analysis using Wilcoxon signed-rank test with a Bonferroni correction. There was a statistically significant difference between agreement degrees for *call* and *weather* entry types, $Z = -2.820$, $p = 0.005$.

After each question participants rated a hint provided as a help to recall the asked information. For this purpose, participants rated the agreement score to the statement "The hint was helpful to remember the quizzed information" on a Likert scale from 1 (strongly disagree) to 7 (strongly agree). Both question and hint were two different entries collected on the same day. Table 6.1 (a) shows the subjective rating of hint and question pairs represented by two different entry types. Because of the number of collected different type of entries, there were not quizzes with some entry types used together as a hint and a question. Those hint and question pairs and pairs that have the same entry type for the hint and question are marked as "–" on the table. We defined four rankings for the hint and question pairs and color coded them. Hints of the pairs assigned to the Rank 1 were rated as the most helpful to recall the asked information. For example, a calendar event was rated as an efficient memory cue for the location information. On the other hand, hints of the pairs assigned to the Rank 4 were rated as the least helpful to recall the asked information. For instance, information about a

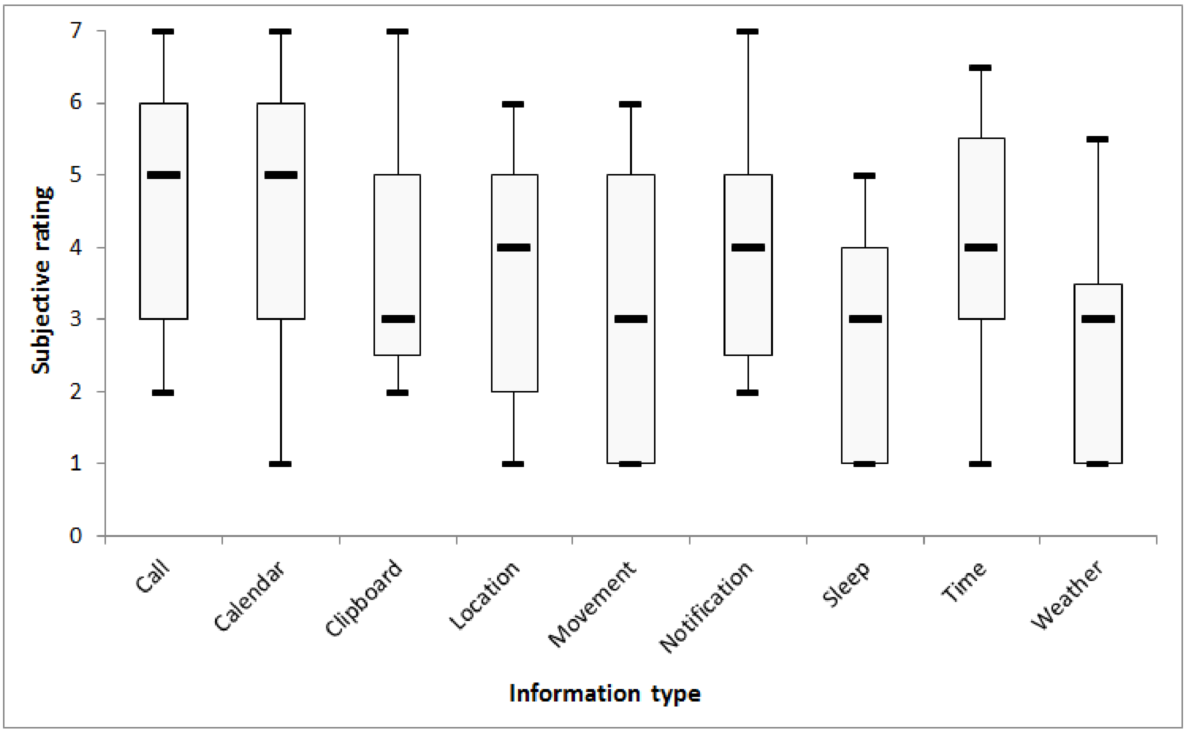

Figure 6.2: Degree of agreement to the statements "<information type> helped me to remember the day" on a Likert scale from 1 (strongly disagree) to 7 (strongly agree).

call as a memory cue was not helpful to recall the sleep behavior. Table 6.1 (b) shows the objective rating of the hint and question pairs. In contrast to the subjective rating, here the average score of quiz results are used. Color coding is the same as in the table illustrating the subjective rating. The hint and question pairs are assigned to the rank 1 if the average score of the quiz results with these pairs is at least 75%. Pairs with the average score of the quiz result less than 25% are assigned to the rank 4. To find a correlation between values of these two tables we ran a Pearson product-moment correlation between them. There was a strong, positive correlation between objective and subjective ratings of the hint and question pairs, which was statistically significant ($r = .532$, $n = 49$, $p < .0005$).

As described in section 4.1.4 the application can generate four different kinds of questions: *who*, *where*, *when* and *what* questions. During the study different number of these kinds of questions were generated. Figure 6.3 shows how participants answered to the different kinds of questions. The average score of the quiz results for *who*, *where*, *when* and *what* questions were 71.365 ($SEM =$), 44.299 ($SEM = 6.264$), 39.315 ($SEM = 4.852$) and 44.812 ($SEM = 2.601$) respectively. To examine the difference in average score of the quiz results for each of question types we ran a repeated measures ANOVA. The dependent variable was mean scores of the quiz results, and question type was the independent variable. Using Greenhouse-Geisser correction we determined that mean scores of the quiz results differed statistically significantly between

(a)

Hint \ Question	Calendar	Call	Clipboard	Location	Movement	Notification	Sleep	Weather
Calendar	--	--	6.00	6.00	2.25	4.75	4.00	5.00
Call	2.00	--	4.75	4.83	3.50	2.40	1.00	3.21
Clipboard	3.50	--	--	2.33	--	1.65	1.00	2.00
Location	3.00	4.07	1.89	--	3.84	3.36	3.40	3.18
Movement	--	3.67	--	--	--	1.50	--	4.00
Notification	4.16	3.67	2.19	3.43	3.17	--	3.20	2.99
Sleep	4.00	4.50	3.50	3.21	4.00	3.85	--	2.67
Weather	2.00	3.16	1.80	3.10	2.92	2.74	2.50	--

Rank 1
Rank 2
Rank 3
Rank 4

(b)

Hint \ Question	Calendar	Call	Clipboard	Location	Movement	Notification	Sleep	Weather
Calendar	--	--	100.00	75.00	50.00	75.00	50.00	100.00
Call	0.00	--	25.00	33.33	50.00	50.00	0.00	21.43
Clipboard	50.00	--	--	16.67	--	70.00	0.00	44.44
Location	66.67	42.86	33.33	--	84.21	64.86	70.00	37.25
Movement	--	83.33	--	--	--	50.00	--	33.33
Notification	50.00	43.75	37.50	44.76	58.33	--	60.00	25.64
Sleep	33.33	75.00	0.00	42.86	52.38	69.23	--	11.11
Weather	0.00	36.84	30.00	48.00	61.53	64.00	66.67	--

Rank 1
Rank 2
Rank 3
Rank 4

Table 6.1: Subjective and objective rating of the hint and question pairs. (a) The table shows the average agreement score to the statement "The hint was helpful to remember the quizzed information" on a Likert scale from 1 (strongly disagree) to 7 (strongly agree). (b) The table shows the average score of the quiz results for every hint and question pairs. Each hint and question pair is assigned to a rank. Rank 1 indicates that the hint is a very helpful memory cue to recall the information asked in the question. On the other hand, rank 4 shows that the hint is the least helpful memory cue to recall the information asked in the question.

question types ($F(2.706, 27.063) = 8.557$, $p < 0.001$). Post hoc tests using the Bonferroni correction determined that mean score of the quiz results for *who* questions was statistically significantly different to those of *where* ($p = .015$), *when* ($p = .014$) and *what* ($p = .011$) questions.

6.2 Qualitative Analysis

All participant seemed to enjoy using the application. They liked to be reminded about past events. In the interview we asked the participants to assess the entry types that the application uses as memory cues. All users reported that received messages were good memory cues. They contain not only information about communicated person but also the context of the

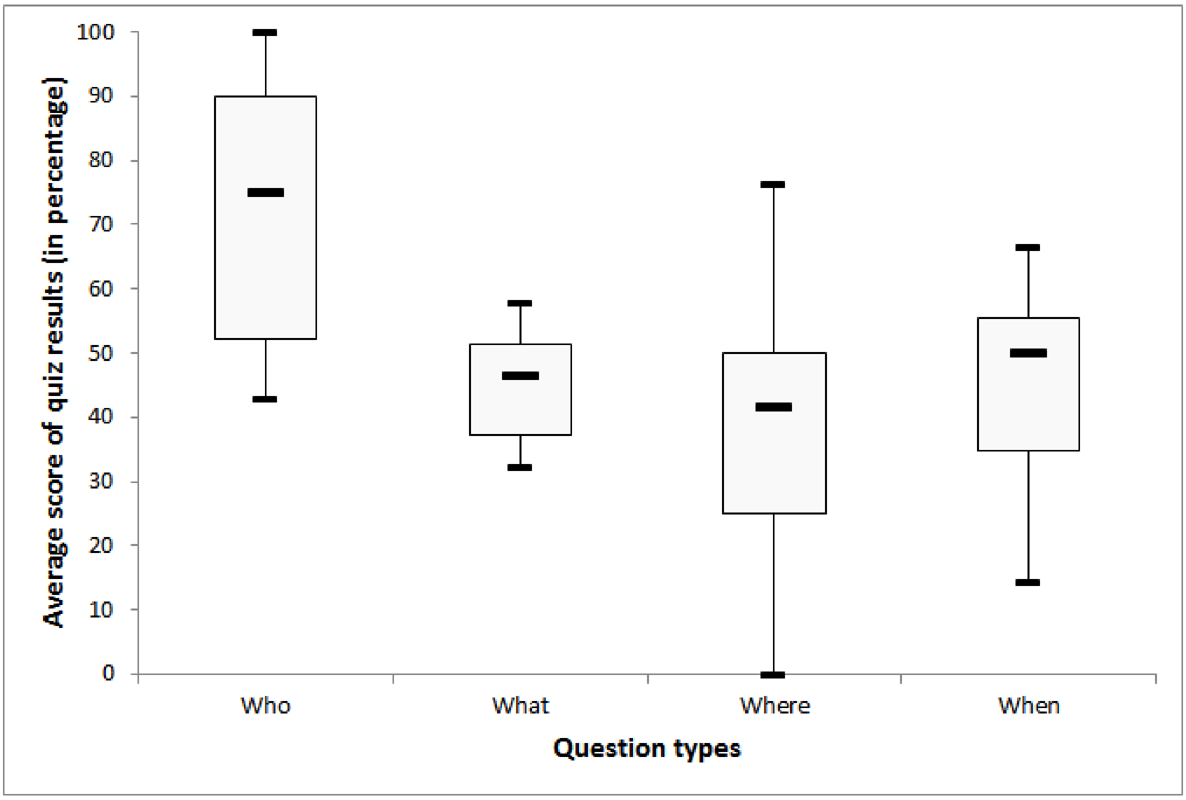

Figure 6.3: Average score of quiz results for each question type.

communication. Reviewing this information helped participants to recall the day that the messages were received. However, some participants reported that not all received messages were important. Therefore, they wanted the possibility to decide the messages manually that the applications records. Information about calls was also useful for participants to recall the day. The number of recorded calls during the study were 48. Therefore, it was easy for participants to recall that information.

Location information was also assessed as a useful memory cue. However, participants reported that the recorded location information must be distinct. The recorded location information was interesting for participants when it was different from the location of their home or work place. Confirming prior work [KSWK10] reflection on location information helped users to reconstruct a memory: "*I saw the location information, and it helped me to remember that I visited my parents. I had forgotten about that.*" Another participant had a similar experience: "*After reviewing a location information I recognized the place where I had gone with my friend. Reflecting on this particular location information helped me to recollect that day.*"

The participants did not find information about sleep, movement and weather helpful. Some users reported that they were not interested in this information. Furthermore, movement and sleep behavior were on workdays almost the same. By looking at these data they could only guess if it had been recorded on a weekend or a workday. Participants also rated time as a valuable contextual information for other memory cues. Smartphone clipboard information was a useful memory cue for 3 participants of the study. They said that clipboard information contains an important textual information for them. Therefore, reflecting on this information can support the recall.

All but two participants reported that reflection affected their mood. It occurred mostly after reviewing received messages. 2 participants said that reflection affected only their temporary mood.

Reflection on implicitly collected information also helped participants to gain new personal insights. Some participants reported that they became aware of their phone usage. They were surprised about the amount of messages they receive a day. Because of that two participants decided to keep their phone away while they are working. The application helped 5 participants to be aware of their sleep and movement behavior. After reflection on this information, they decided to change their movement and sleep behavior to achieve their defined goals.

6.3 Summary

In this work, we presented an Android application that implicitly collects personal related data and prompts users to reflect on them. To find out the impact of reflection on implicitly collected data we conducted a study with 11 participants. The majority of related work has investigated tools that collect explicitly data to support the recall. The results of the evaluation showed that implicitly collected data can also support the recall. The result of the subjective rating of information types collected by the application showed that user's communication data, calendar events, time and location information can be used as memory cues. Furthermore, clipboard information, weather information, movement and sleep data can be used together with other memory cues to support the recall. On top of that, we found that what information type can be used as an efficient memory cue for other information types. For example, calendar event is an efficient memory cue for a location information.

The results of the study showed that reflection improves recall. To measure the recall we used the score of the quiz results. We compared the average score of the quizzes that asked questions about reflected and non-reflected entries. The mean result of the quizzes with questions about reflected entries was significantly higher than another one.

A limitation of our study was that 8 days delay between the first part (Collection phase) and the second part (Quiz phase) of the study. A long-term study is needed to understand how reflection on collected entries affects recall. Another limitation was the number of participants.

7 Conclusions

In this thesis, we introduced the concept to evaluate the impact of reflection on implicitly collocated data on recall. First, we discussed related work regarding episodic memory. Tulving [Tul93] proposed that episodic memory allows people to mentally time travel and consciously re-experience past occurrences. Afterward, we discussed various memory cues that investigated in previous work to support episodic memory. We then looked at the recent research regarding reflection. Furthermore, we discussed benefits of using reflection on the fields of education, design and healthcare. Moreover, we discussed several commercial products that facilitate people to record personal information and reflect on it.

Based on the described related work we proposed the concept of ReflectiveDiary. ReflectiveDiary is an Android application that supports users to reflect on implicitly collected information about them. Its features enable automatic collection of several personal information using various sources. The application records information about user's sleep and movement behavior, visited places and weather information for these locations, communication data, calendar events and smartphone clipboard data. Furthermore, ReflectiveDiary explicitly collects user's happiness rating. ReflectiveDiary not only collects information but also uses Android's notification feature to prompt users to reflect on it. Another feature of the application makes it possible users to quiz their knowledge about the collected data on previous days. The quizzes are automatically generated and are based on already recorded user's information. In chapter 3 we discussed how the application collects and visualizes the personal information. Furthermore, in chapter 4 we discussed the implementation of above-mentioned features of ReflectiveDiary.

To evaluate the concept we conducted a user study with 11 participants. The application collected overall more than 7000 recordings. Using the collected data, we analyzed the impact of reflection on implicitly collocated data. We found that average quiz result was significantly higher when the quiz based on entries that users reflected on. We can conclude from this findings that reflection improves the recall. Furthermore, we analyzed which collected memory cues were helpful for supporting the recall. We found that participants rated communication data, calendar events, time and location information as a helpful memory cue. During the study, the application created four types of questions for quizzes. In these questions, person, place, time or contextual information were asked. We observed that participants answered questions about person better than questions about the place, time or contextual information.

7.1 Future Work

Prior work [Con09] proposes that episodic memory preserves the temporal order of the occurrence of events. Therefore, the application represented all recorded information in the temporal order. Participants said that when there were too many entries, it was difficult to follow each memory cue. This limitation was noticed by several participants. A feature that enables grouping of entries was missing in ReflectiveDiary. Furthermore, some participants proposed a feature that allows users to manually choose notifications of which applications to be recorded.

Received messages can contain valuable information to recall previous days. In the application, each collected message was represented on the list. Not all received messages contain valuable information. Therefore, we can build a feature of the application that analyzes their content and records if they contain valuable memory cues. Furthermore, using the finding various type of tools can be created. We found that reflection improves recall. This finding, for example, can be used to create a learning tool that prompts users to reflect on the tutorials.

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Decleration

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

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