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Designing Ubiquitous-Computing Systems for Memory Alterations

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ABSTRACT

Human memory shapes an individual's identity and reactions, driving the progress of civilizations through shared knowledge. Human-Computer Interaction research has focused in the past thirty years on augmenting human capabilities including memory to create "super humans". However, the increasing digital resources competing to generate content and alter what we remember threaten our natural mechanisms for forgetting inessentials and focusing on what is important. To this end, the aim of this thesis is two-fold: (1) understand the design process of memory-altering ubiquitous computing systems (MACS), and (2) raise awareness about accidental alterations resulting from using existing technologies. Memory alterations in this context refer to memory augmentation and reformation (including memory degradation and implantation). We differentiate between active systems primarily acquired for memory alterations and ambient systems where the alteration is a byproduct of the usage and the user might not be aware of it. The primary goal of our work is to understand: (1) how to design MACS, (2) how to conduct privacy-aware memory research, and (3) the users' expectations towards utilizing their memories by other users and intelligent systems. With the help of 188 participants, we achieve our goal by designing eight research projects in the domains of lifelogging, social media, gamification, and implicit sensing using Brain-Computer Interfaces.

We consolidate the design insights from the eight projects and present a framework for designing MACS. The framework defines the memory alteration strategy, technical parameters via *MemAlt* pipeline, and the media selection of the memory cues. We learnt the following: (1) that treating capturing devices as social beings rather than passive tools could overcome capturing conflicts with bystanders, (2) that domain-specific augmentation is preferable to "total-recall" visions, (3) that direct proxies from incidents are preferable for augmentation, (4) that the difference between first-person and third-person captures can be used for reformation, (5) to use fewer cues for augmentation and more altered cues for reformation, and (6) that blurring is suited for reformation as it may be good to remember a forgotten topic without necessarily recalling relevant accurate details.

We contribute to privacy-aware memory research by developing two methods, namely Concealed Memory Collection (CMC) and Automated Memory Validation (AMV), to anonymously collect and evaluate free recall and cued details by matching them to ubiquitously-collected ground truth data. We also extend a third metric called Recall Correctness Score (RCS) to score recognition and

recall. Lastly, we identify a hazard in designing input and merit systems that can tamper with the validity of experimental data in mobile games .

We contribute to understanding the sharing expectations using niche social media projects to foresee future patterns with experimental technologies. A primary sharing pitfall with other users is underestimating the reachability of the shared memories resulting in negative social repercussions. Users are apprehensive about intelligent system interactions that are monetizable, and less appreciative of smart interactions cuing their offline interactions.

The contributions of this thesis make designing MACS more accessible to researchers, and allow system designers to reflect on the potential adverse effects of their designs on the human memory. With the prevalence of tracking devices such as mobiles, fitness devices, and smart home gadgets, we envision a future where domain-specific MACS are ubiquitously embedded in the user's every day interactions. We particularly encourage future research in the direction of ambient augmentation for cuing social interactions and communication, and exploring the benefits of MACS in aiding psychiatrists during cognitive behavioural therapy. We also encourage further investigation to identify current accidental memory reformations that result in excessive technological interventions, to enable purposeful and safe interactions with ubiquitous-systems.

ZUSAMMENFASSUNG

Das menschliche Gedächtnis macht die Identität und die Reaktionen eines Individuums aus und treibt den Fortschritt der Zivilisationen durch geteiltes Wissen voran. Die Forschungen der Mensch-Computer-Interaktion (MCI) haben sich in den letzten dreißig Jahren darauf konzentriert, die menschlichen Fähigkeiten inklusive des Gedächtnisses zu erweitern. Digitale Ressourcen generieren zunehmend Inhalte und verändern an was wir uns erinnern. Dies steht in Konkurrenz zu unseren natürlichen Mechanismen, die uns erlauben Unwesentliches zu vergessen und uns auf das Wesentliche zu konzentrieren. Daher leiten sich die zwei Ziele dieser Dissertation ab: (1) den Designprozess von allgegenwärtigen Computersystemen mit Gedächtnisveränderungen (Memory-Altering ubiquitous Computing Systems, MACS) zu verstehen und (2) Bewusstsein für versehentliche Gedächtnisveränderungen, die sich aus der Verwendung bestehender Technologien ergeben, zu schaffen. Gedächtnisveränderungen beziehen sich hierbei auf Gedächtniserweiterung und –reformation, inklusive Gedächtnisverschlechterung und dem Einfügen von Erinnerungen. Dabei wird zwischen aktiven Systemen unterschieden, die hauptsächlich für Gedächtnisveränderungen veranlagt wurden, und Umgebungssystemen, bei denen die änderung ein Nebenprodukt der Nutzung ist und Benutzer sich dessen möglicherweise nicht bewusst sind. Das primäre Ziel dieser Arbeit ist es folgendes zu verstehen: (1) der Entwurf von MACS, (2) die Forschung an Erinnerungen unter Berücksichtigung der Privatsphäre und (3) die Erwartungen von Nutzern in Bezug auf die Verwendung ihrer Erinnerungen von anderen Nutzern und intelligenten Systemen. Dieses Ziel wurde erreicht mit der Hilfe von 188 Teilnehmern und der Entwicklung von acht Forschungsapparaten in den Bereichen Lifelogging, soziale Medien, Gamification und implizite Sensorik mit Gehirn-Computer-Schnittstellen (Brain Computer Interface, BCI). Designeinblicke der acht Untersuchungen werden in dieser Arbeit vertieft und es wird ein Rahmenwerk für die Entwicklung von MACS präsentiert. Das Rahmenwerk definiert die Strategie der Gedächtnisveränderungen, die technischen Parameter über die “MemAlt”-Pipeline und die Medienauswahl der Abrufhilfen. Daraus leiten sich die folgenden Erkenntnisse ab: (1) Aufnahmegeräte als soziale Wesen und nicht als passive Werkzeuge zu betrachten kann Aufnahmekonflikte mit Umstehenden überwinden, (2) die domänenspezifische Gedächtniserweiterung wird einem “vollständigen Abru” von Erinnerungen bevorzug, (3) direkte Proxys von Vorfällen werden für die Gedächtniserweiterung bevorzugt, (4) Unterschiede zwischen Aufnahmen in erster und dritter Person können für die Reformation benutzt werden, (5) weniger Abrufhilfen für die Gedächtniserweiterung und mehr veränderte Abrufhilfen für die Reformation verwenden und (6) Verzerrung ist

für Reformation geeignet, um sich an ein vergessenes Thema zu erinnern ohne sich notwendigerweise genaue Details zu erinnern. Diese Arbeit trägt zur Gedächtnisforschung mit einem Fokus auf Privatsphäre durch die Entwicklung von zwei Methoden bei. Concealed Memory Collection (CMC) und Automated Memory Validation (AMV) ermöglichen anonyme Details des freien Erinnerns (Free Recall) beziehungsweise des Erinnerns mit Abrufhilfe (Cued Recall) zu sammeln und auszuwerten, indem sie mit allgegenwärtig gesammelten Ground-Truth-Daten abgeglichen werden. Weiterhin wurde eine dritte Metrik namens Recall Correctness Score (RCS) erweitert, um die Wiedererkennung und den Recall zu bewerten. Abschließend wir eine Gefahr bei der Entwicklung von Eingabe- und Leistungssystemen identifiziert, welche die Gültigkeit von Experimentdaten in mobilen Spielen manipulieren kann. Es wird ein Verständnis für die geteilten Erwartungen in kleineren sozialen Netzwerken entwickelt, um neue Muster in experimentellen Technologien vorherzusagen. Eine primäre Falle beim Teilen mit anderen Benutzern ist die Unterschätzung der Erreichbarkeit der geteilten Erinnerungen, was zu negativen sozialen Auswirkungen führt. Benutzer haben Bedenken gegenüber intelligenten Systemen welche monetarisiert werden können und zeigen weniger Wertschätzung für intelligente Systemhandlungen, welche auf ihr “offline” Verhalten verweisen. Die Beiträge dieser Dissertation machen das Entwerfen von MACS für Forscher zugänglicher und ermöglichen es Systemdesignern über die möglichen negativen Auswirkungen ihrer Designs auf das menschliche Gedächtnis nachzudenken. Mit der Verbreitung von Tracking-Geräten wie mobilen Endgeräten, Fitnessgeräten und anderen intelligenten Geräten ist eine Zukunft denkbar, in der domänenspezifische MACS überall im Alltag des Benutzers eingebettet sind. Dies fördert insbesondere zukünftige Forschungen in Bereich der ambienten Erweiterungen für Hinweise auf soziale Interaktionen und Kommunikation und die Erforschung der Vorteile von MACS bei der Unterstützung von Psychiatern während der kognitiven Verhaltenstherapie. Außerdem werden weitere Forschungen zur Erkennung von versehentlichen Gedächtnisreformationen unterstützt, die zu übermäßigen technologischen Eingriffen führen, um zielgerichtete und sichere Interaktionen mit allgegenwärtigen Systemen zu ermöglichen.

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PREFACE

The work in this thesis was created between 2016 and 2021 during employment in the German University in Cairo (GUC), the University of Stuttgart (USTUTT), and Ludwig Maximilian University of Munich (LMU Munich) respectively. The work done here was mainly inspired by the RECALL project and developed during the AMPLIFY project. The work done here was part of a state scholarship to support research collaborations in the field of digital media and technology. The interdisciplinary nature of the research topic lying on the intersection of Psychology, Computer Science, and Engineering led to several collaborations with research partners and experts. Most of the collaborations were from employment institutes in addition to the University of Glasgow, and international research partners from the RECALL project such as the University of Lancaster, University of Essex and Università della Svizzera Italiana. The other contributing authors for each project are clearly stated at the beginning of the chapters along with citations to the publications whenever possible. This work would have not been possible without such valuable collaborations. Thus, the pronoun “we” is used throughout this manuscript to refer to the collective work of the research team as a way to thank them and acknowledge their efforts.

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Foundation

Chapter 1

Introduction

In this thesis, we contribute to extending the capabilities of humans by amplifying their cognition. We achieve this goal by designing technologies that alter the human memory to facilitate imparting knowledge and reflecting on past experiences. In this chapter, we start by explaining the motivation for our work. Afterwards, we present the research questions and contribution of this thesis, then we highlight the research context of the work and other relevant publications not covered within this manuscript. Lastly, we introduce an overview of the structure used to answer the research questions.

1.1 Motivation

Memory is our primary reference to past experiences and learnt lessons. It also influences our emotions and how we perceive individuals and concepts. Therefore, it is one of the pillars that affect the decision making process and shape one's character. Despite its crucial role, it is prone to fundamental caveats. Schachter et al. identified seven "memory sins" that distort our recall of past events [226]. They showed that people suffer from natural gaps in capturing information due to lack of attention (absent-mindedness), and their memories tend to naturally decay over time (transience). Furthermore, their emotional state could distort the original memory of past events (bias). For example, people selectively recall memories to generalize whether they were happy or not in a relationship based on

their present emotional states. Moreover, there is a tendency to confuse the source of one memory with another (misattribution) as well as mix false suggestions made by others with the original memory (suggestibility). For example, someone could think they had met their best friend in a summer camp though they met in school. These natural memory shortcomings could result in unprompted reactions to situations and possibly lead to grave consequences. An example is faulty testimonies from eye witnesses cued by the media narrative about an ongoing case.

Individuals have long used memory augmentation strategies to overcome such shortcomings, preserve their knowledge and enhance their decision making processes. For example, they may have explicitly documented their lives through diaries, paintings and photos to ensure they preserved what seemed important at the moment in a personalized and digested manner. However, this does not account for the changing importance of events over time nor the implicit memory shortcomings in any belated documentation. Harburda's work conforms with this approach and he presented seven "penances" to overcome Schachter's "sins" [115]. The penances included taking notes from important events daily and obtaining the information quickly after an event, when it was fresh in people's minds. The early trials of memory augmentation were centered around creating knowledge databases that we could reference on demand later as an external memory prosthetic. A common strategy today for creating such prosthetic conforming with the penances is using the "Lifelogging" concept. Lifelogging is the action of fully capturing a person's life through cameras and other sensors to "never miss a moment". Lifelogs are objective comprehensive digital archives of cues to a person's memories. Sellen and Whittaker summarized the benefits of lifelogging after a meta-review for existing systems [228]. Lifelogging facilitates critical assessment of past experiences through reliving them, and helps in reminiscing over specific memories for emotional and sentimental reasons, or retrieving specific, almost forgotten old information. It also assists in reasoning about past experiences by representing an abstract and interconnected version of multiple experiences. It could also highlight the intentions for future actions like keeping a person motivated to go to the gym. One of the earliest breakthroughs about lifelogging was "My Lifebits"[1] project by Gordon Bell and Jim Gemmel [29] . This was one of the first systems realizing the vision of "total recall" in health, work and personal life and investigating its effects in real scenarios.

The large amount of captured heterogeneous data in the external memory prosthetic (e.g. social media content, photos, emails and appointments) poses a great

[1] https://www.microsoft.com/en-us/research/project/mylifebits/

challenge to search and present the adequate memory cues on demand. For example, Wactlar et al. showed that the key aspect for successful and useful access of information in lifelogs of video streams is the ability to "index, search and meaningfully summarize and visualize the captured data" [259]. On one hand, the processing is computationally expensive. On the other, semantically understanding and selecting the content based on heuristics is still an ongoing struggle. This is reflected in Gordon Bell's statement about the "My Lifebits" project: "the hard part is no longer deciding what to hold on to but how to efficiently organize it, sort it, access it and find patterns and meaning in it" [29].

As the research endeavours to augment the memory progressed, a parallel approach emerged targeting the reversal of the sins on a human level and inherently enhancing how we recall events. Psychological strategies like repetitive reviewing of content were adopted by ubiquitous-computing systems (UCSs) to reduce memory decay (e.g.: [90, 227, 116]). We refer to such systems as solutions doing *active memory augmentation* because the users utilize them with the primary goal of remembering more. The next step was experimenting with implicitly imparting knowledge to individuals through systems. A trivial example is how people accidentally memorize parts of advertisements because of the way the advertisement is presented. We refer to such systems as solutions doing *ambient memory augmentation*, as the augmentation happens discreetly without the user's explicit consent.

The prevalence of ubiquitous-computing technologies serving as memory aids to various degrees amplified the portable knowledge of people at a given time. For example, in the modern era, one has access to several hundreds of phone numbers instantly ready to use and fast to find instead of relying on limited human recall or unindexed phone books. However, the potential downside to this technological revolution is accentuating the memory decay and sins in episodic memories accidentally (e.g. [68, 237, 250]). For example, younger generations are less likely to memorize a phone number or an address as the norm is to have it on the mobile phone. Imagine the stressful scenario where the phone battery dies on the way to visit a friend at a new location and the person has no access to their phone number and address. Such effects of extensively using ubiquitous-computing interventions on decaying memory are currently underexplored in the literature. An alternative perspective is intentionally using non-invasive technological interventions to invoke memory decay. In the context of this manuscript, memory decay refers to forgetting by reducing the recall quality and quantity, or memory implantations resulting from Schacter's sins like misattribution and suggestibility where the person believes an event happened in one context when it did not. This could be done for malicious reasons such as

convincing a person with a twisted version of an event or for beneficial reasons such as helping post traumatic stress disorder patients block painful memories.

In this thesis, we explore *how we can design UCSs that support memory alterations including augmentation, attenuation, and implantation*. We believe our work offers a timely contribution as the scientific community strives to amplify human capabilities, especially cognition and memory, as an integral component to achieving this goal. Additionally, it guides future work in building memory-aware ubiquitous-computing systems that protect the human memory against accidental unprompted alterations.

1.2 Research Questions

The objective of this thesis is *two-fold*: (1) explore how we can design UCSs that alter human memories, and (2) raise awareness about the impact of existing technologies on reforming memories. We use and develop research methods that borrow from the literature of Psychology and Engineering to develop privacy-aware user-centered approaches to experimenting with human memory. Our work focuses on technical recommendations for developing the systems justified by existing Psychology literature rather than reporting on new psychological findings. We divide UCSs into two categories: active and ambient. *Active systems* refer to solutions with the primary objective of altering memories where the user uses them explicitly for this objective. *Ambient systems* refer to solutions where memory alteration happens indirectly through interacting with the system without users originally owning it for that goal. To narrow the research domain, we target two memory strategies for altering memories: augmentation and reformation (including attenuation and implantation). In this manuscript, we aim to answer *five* research questions (RQs) related to Memory-Altering ubiquitous-Computing Systems (MACS):

RQ1 What are the parameters for designing MACS?

RQ2 How to conduct privacy-aware memory research using MACS?

RQ3 How to design active MACS?

RQ4 How to design ambient MACS?

RQ5 How do users expect their shared memories to be used on MACS?

1.3 Contribution

The work presented in this thesis produces *nine* contributions to the field of Human-Computer Interaction (HCI). They are divided into *three* categories: technical, methodological, and empirical contributions.

1. **Technical contribution** We built and designed the following:
   (a) **"Life-Dome" prototype** This is a prototype for reviewing at-a-glance large datasets of pictorial lifelogs to support reflection and search. We use it to review weekly lifelogs composed of ca. 9701 photos in total. The prototype is presented in Section 6.1.1.
   (b) **Design framework** This is a framework for designing UCSs for altering memories. It incorporates the findings of all the research projects in this thesis, and can be used as a design tool to build new systems or as a reflection tool to compare several systems. It is comprised of three parts: memory strategy, *MemAlt* pipeline, and media selection. The *memory strategy* part is the system approach to altering the memories of the users (e.g. augmentation, attenuation or implantation). The MemAlt *pipeline* is a technical pipeline summarizing the parameters for designing the systems divided across several layers. The *media selection* part offers parameters for selecting appropriate media types to present a memory cue in a system. The framework is presented in Chapter 3.
   (c) **Design guidelines** We compile a list of design guidelines based on the system type (active vs. ambient) and the memory strategy to answer the research questions. The guidelines are discussed in Chapter 11 and 12.
2. **Methodological contribution** We extended existing literature methods and created the following new methods:
   (a) **Recall Correctness Score (RCS)** This is a scoring system to detect the quality and quantity of recalled memories. The metric is discussed in Section 5.2.3 and 9.2.4.
   (b) **Concealed Memory Collection (CMC)** This is a method for collecting memories in a privacy-aware experimental setup without exposing the content of the recalled details to researchers. We use computerized systems to achieve this goal. The method is discussed in Section 5.2.1 and 6.1.2.

(c) **Automated Memory Validation (AMV)** This is a method for validating memories in a privacy-aware experimental setup without exposing the content of recalled details to researchers. We achieve this through designing a lifelogging system for the users then using the ubiquitously collected data to validate the concealed memories collected using the Concealed Memory Collection (CMC). The method is discussed in Sections 5.2.2 and 6.1.2.

(d) **Transforming memory experiments to games** This is a set of guidelines for specifically transforming memory laboratory experiments to in-the-wild mobile games to avoid tampering with the experimental validity through game design elements. The guidelines are discussed in Section 5.2.4.

3. **Empirical contribution** We present new user attitudes while interacting with technological interventions in the following domains:

   (a) Understanding the impact of privacy-protection methods on reforming memories. We discuss this in Chapter 9.

   (b) Understanding the impact of smart systems using users' memories implicitly on the likeability of the system and the interaction quality. We discuss this in Section 10.2.

1.4 Research Context

The work done during my doctorate degree between 2016-2021 was during my employment in three research institutions: The Human-Computer Interaction research group in the University of Stuttgart (hosting university), The Human-Centered Ubiquitous Media research group in Ludwig Maximilian University of Munich (LMU Munich), and the Faculty of Media Engineering and Technology in the German University in Cairo (GUC). It is a result of close interdisciplinary collaborations with colleagues encompassing engineers, computer scientists, and psychologists within the three research groups and outside it.

The work was partially funded by two consecutive scholarships. The first is the bilateral DAAD scholarship[2] for university projects abroad between the GUC and its partner the University of Stuttgart. The second[3] is the Baden- Württemberg

[2] Official name: DAAD Hochschulprojekte im Ausland

[3] Official name: Kooperatives Promotionskolleg Digital Media

state scholarship for collaborations between the state universities and Hochschule Der Medien in Stuttgart. Additionally, the work was conducted and also partially funded within the scope of two larger projects: (1) AMPLIFY and (2) RECALL, and two external collaborations on research projects: (1) Serious Games for Education and Sustainable Development and (2) Affect my life. The projects are presented in reversed chronological order starting with the most recent.

AMPLIFY

This[4] is the main project driving the work done in this thesis. The project was funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (ERC Consolidator Grant no.683008). It was led by LMU Munich in Germany, and aimed at creating artificial human senses and augmenting existing ones through building new perceptual channels for imparting information. My role was evaluating the impact of technologies on altering memories. This was done through a series of user studies to understand user behaviours around several technological interventions.

RECALL

This[5] project was my initial inspiration for working in the domain of memory alteration. The project was funded by the Future and Emerging Technologies (FET) program with the Seventh Framework program for research of the European Commission (FET grant no. 612933). It was led by the University of Lancaster in the United Kingdom in collaboration with the University of Stuttgart in Germany, University of Lugano in Switzerland, and University of Essex in the United Kingdom. The project was centered around redefining the notion of memory augmentation through designing interventions that implicitly augment the human memory without requiring an external memory prosthetic. My role was building and deploying prototypes to leverage lifelogging technologies for memory augmentation.

[4] http://amp.ubicomp.net/

[5] https://recall-fet.org/about/

Serious Games for Education and Sustainable Development

This[6] project was my initial collaboration with the research group in Stuttgart. The project was funded by DAAD-BMBF project "Sustainable Research Cooperation with the German University in Cairo (GUC)". The project was led by the German University in Cairo (GUC) in collaboration with the University of Stuttgart in Germany, LMU Munich in Germany, DHBW[7] Stuttgart, and DHBW Karlsruhe. The project focused on developing games for the purpose for education and developing the community in Arabic-speaking countries. My role was developing games for supporting education and memory.

Affect My Life

This project inspired my line of research about memory reformations. It was also led by the German University in Cairo (GUC) in collaboration with the University of Stuttgart, LMU Munich, DHBW Stuttgart, and the state-of-the-art company for affective computing solutions Affectiva. The project focused on developing affective computing to leverage self awareness and augment human cognition. My role focused on the presentation of mental states to support emotional awareness.

Research Outcome

Parts of this thesis has been published in 11 publications in scientific conferences and workshops such as [75, 76, 78, 79, 80, 81, 82, 83, 84, 99, 219]. The contribution declaration of the dissertation's author is listed later in Section 4.1.

There are other publications for the author in scientific conferences and workshops that are beyond the scope of this thesis in domains such as: serious games [108, 176], social virtual reality [272, 271],ambient nudges towards social interactions [74] andlifelogging and tracking [56, 64, 65, 67, 192].

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[6] https://met.guc.edu.eg/Research/Division.aspx?resFieldId=50

[7] Duale Hochschule Baden-Württemberg

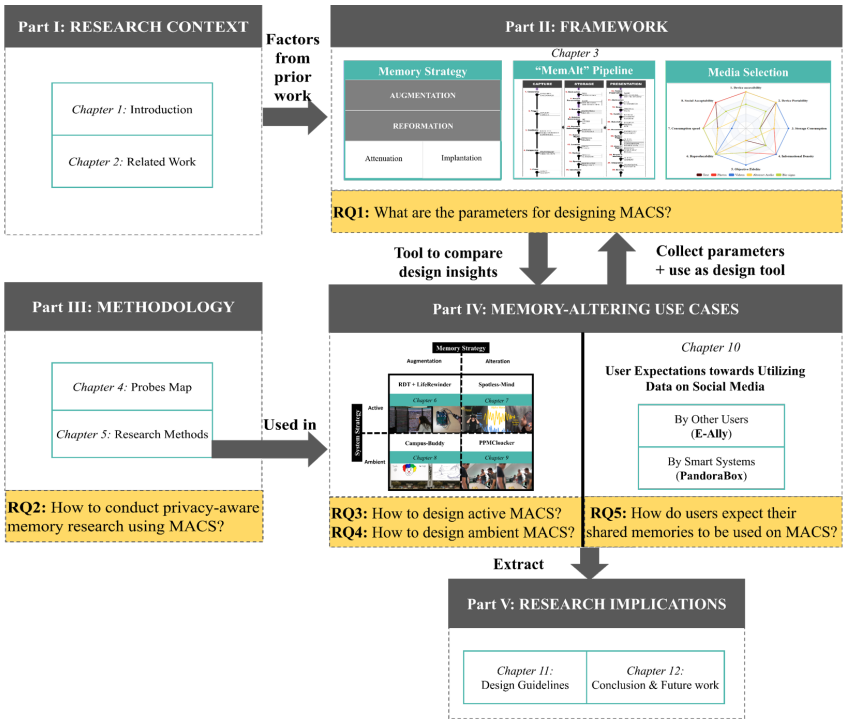

Figure 1.1: Summary of the thesis structure. The thumbnails are expanded in their respective chapters.

1.5 Thesis Outline

This thesis is presented in twelve chapters grouped into four parts followed by a bibliography and an appendix. The thesis structure is summarized in Figure 1.1. We present below a short summary for the contents of each chapter.

Part 1: Research Context This covers the motivation of this work as well as how it builds on existing literature.

Part 2: Framework Design This introduces a framework to build and evaluate MACS. The framework is distilled from literature and our experiences designing research projects in Part IV. In this part, we answer **RQ1**.

Part 3: Methodology This presents an overview on the research methods used and the research projects implemented to deduce the components of the framework. In this part, we answer **RQ2**.

Part 4: Memory-Altering Use Cases This comprises five research projects to understand the design parameters for MACS. Each chapter overs a use case for memory alteration to answer **RQ3 and RQ4**. We use the aforementioned framework twice for each project: once at the beginning to summarize the design decisions in implementing the system and another at the end to summarize the findings and lessons learnt about the design process. The projects were used collectively to deduce the parameters of the framework in Part II. Additionally, we answer **RQ5** using social media as an example for niche MACS.

Part 5: Research Implications This summarizes the guidelines we learnt about designing MACS and answers the research questions proposed here. In this part, we consolidate the findings from **RQ1** $\longrightarrow$ **RQ5**.

Part 1: Research Context

Chapter 1 - Introduction This chapter covers the motivation of the work presented in this thesis as well as the research questions. It also lists the contribution of this thesis and the collaborations within the conducted work.

Chapter 2 - Background and Related Work This chapter summarizes the necessary background about commonly used terminology and the nature of memory cues, then offers an overview on the usage of different media types to present memory cues and how it impacts recall. Afterwards, we present a review of privacy protection methods in MACS, a review about gamification of memory experiments, and finally, a review about usages of large displays in memory-altering systems.

Part 2: Framework Design

Chapter 3 - MACS Framework Design This chapter is derived from our work in the upcoming chapters. However, we present it early on to lay a mental model for discussing various MACS. The framework is comprised of three components: memory strategy, *MemAlt* pipeline for technical development, and media selection. It answers **RQ1** about design parameters for MACS.

Part 3: Methodology

Chapter 4 - Research Projects Map This chapter introduces the eight research projects presented in this thesis. It shows the criteria for choosing specific use cases for memory alterations. Additionally, it provides a short guide for each project presenting an abstract description, collaboration and contribution statement, and used research methods.

Chapter 5 - Research Methods This chapter summarizes the research methods used in all projects. It provides a quick overview on standard research methods then explains the methods we developed to fit our research constraints. In this chapter, we introduce one metric Recall Correctness Score (RCS), two methods CMC and Automated Memory Validation (AMV), and a set of design guidelines derived from the research project **PrisonerOfWords** for transforming laboratory experiments into mobile games. It answers **RQ2** about conducting privacy-aware memory research.

Part 4: Memory-Altering Use Cases

Chapter 6 - Memory Augmentation via Lifelogging This chapter covers the research projects **Recall Domestic Trial (RDT)** and **LifeRewinder**. It is a use case for MACS using active memory augmentation. **RDT** is a one-month deployment of a lifelogging toolkit followed by a privacy-aware memory examination laboratory protocol. The protocol is a practical application of the methods proposed to answer **RQ2** in Chapter 5. **LifeRewinder** is a prototype using haptics to optimize interactions with pictorial lifelogs. This chapter offers insights about **RQ3** related to designing active MACS.

Chapter 7 - Memory Reformation via Symbiotic Sharing This chapter covers the research project **SpotlessMind**, and presents a use case for active memory reformation. This is a Brain-Computer Interface (BCI) installation that allows two people to share a mental state that is brain occupancy while bystanders watch them. We consider brain occupancy a proxy for thinking about memories. We envision using the system to reach a state of symbiotic equilibrium where the mental state of one person affects the other's state and changes it. The chapter also offers insights into **RQ3** related to designing active MACS.

Chapter 8 - Memory Augmentation To Feel Familiar This chapter presents the research project **CampusBuddy**. It is a use case for ambient memory augmentation, and describes a user study about selection of content on public

displays in a university campus to create a sense of familiarity. The chapter offers insights about **RQ4** related to designing ambient MACS.

Chapter 9 - Memory Reformation via Lifelogging This chapter presents the research project **PPMCloak**. This is a user study about the impact of privacy-protection method used for lifelogging photos on the recall quality and quantity. Through this chapter, we show an ambient memory reformation use case. The chapter also offers insights about **RQ4** related to designing ambient MACS.

Chapter 10 - Shared Memories on Social Media This chapter presents an overview on the user expectations and concerns of smart systems when they share their memories on such systems. We particularly focus on the user expectations towards: (1) other people utilizing their shared memories and (2) smart systems utilizing the shared memories to perform intelligent interactions. This chapter offers insights about **RQ5** related to the user expectations about data utilization on MACS.

Part 5: Research Implications

Chapter 11 - Design Guidelines for MACS This chapter sums up abstract design guidelines to pull together the findings from **RQ3, RQ4, and RQ5**. This chapter combined with Chapter 3 provides the basis for the design knowledge we collected through our work to answer **RQ1**.

Chapter 12 - Conclusion and Future Work This chapter provides a summary and condensed reflection on the answers of the research questions. Additionally it highlights promising future research directions to further develop MACS.

Appendices

Appendix A - Framework Insights Summary This appendix summarizes all the design insights from the research projects and maps them to the parameters of *MemAlt* pipeline.

Chapter 2

Background and Related Work

In this chapter, we present the foundation of our work. We introduce to the reader our research context by presenting relevant technologies to the upcoming projects in this thesis. The chapter is structured as follows:

Memories in Psychology First, we introduce the fundamental background about the formation of memories and how we remember information from a psychological perspective. Afterwards, we discuss common memory cues in HCI research and we reflect on the implications of media types presenting memory cues on the quality of remembered memories.

Research Inspirations We pinpoint some of the recent research teams that their work highly inspired our work on memory alterations. This list is not meant to be exhaustive by any means. However, it serves as a starting point for the reader to get involved in the trail of current work.

Memory Augmentation via Lifelogging We reflect on a particular holistic approach for memory alteration, that is lifelogging. We focus on lifelogging despite the presence of other approaches as we have several research projects in this thesis researching it's aspects. Lifelogging is commonly used in the context of active memory alterations.

Memory Reformation and Ubiquitous Technologies We offer an overview on current technological and psychological interventions for accidental and deliberate memory reformations. Next, we highlight the research gaps in the area motivating our work.

Technologies Aiding Memory Alterations We select two technologies that can be used for memory alterations: (1) BCIs for capturing recall markers, and (2) large displays for presenting memory cues for ambient memory alterations.

Privacy of Captured Pictorial Cues We focus on privacy preservation in near-continuous capture pictorial systems as they pose frequent accidental violations to bystanders. We particularly discuss post-capturing solutions as they are widely used in industry and research as they are easy to configure and apply.

Sharing We summarize sharing patterns and behaviors in common MACS. We particularly focus on sharing in the context of social media because it is a niche widely-used MACS. Thus, we can reflect on realistic usage patterns to foresee future patterns with current lab technologies.

Parts of this chapter are based on the following publication(s):

- V. Gentile, P. El Agroudy, E. Ergin, and S. Clinch. Pervasive displays research: What's next? *IEEE Pervasive Comput.*, 18(1):72–78, 2019
- P. Elagroudy, X. Wang, E. Stemasov, T. Hirzle, S. Shishkovets, S. Mehrotra, and A. Schmidt. Spotlessmind: A design probe for eliciting attitudes towards sharing neurofeedback. In *Proceedings of the Augmented Humans International Conference, AH 2020, Kaiserslautern, Germany, 16-17 March, 2020*, pages 24:1–24:8. ACM, 2020

2.1 Memories in Psychology

In this section, we summarize the key psychological concepts that this work is based on. We first present a definition for what is considered a memory and how we remember information, then we present a summary of why we forget information. We recommend the reader to check Baddeley et al.'s work [26] explaining basic concepts about memory and how we learn information for an in-depth background review of the topic.

2.1.1 Definition of Memories

In this manuscript, we define *"memory"* as any thought that is related to a past incident. The thought could be related to details of the event itself or relevant emotions before, during or after the event, or meta reflections and lessons understood because of the event. There are three common types of long term memories: episodic, procedural, or semantic memories[26]. *Semantic memories* refer to our knowledge about the outside world. It includes the facts we learn in school, for example, about general topics such as science and social studies. It builds a schema of knowledge that we can use later to add and categorize further information. It also involves a layer of logical findings from synthesizing several experiences. An example is the ability to solve a mathematical problem by selecting and recalling the appropriate relevant rules then solving the problem using the recalled abstract concepts. On the other hand, *episodic memories* refer to the recollection of a personal event or incident. It is the type of memory responsible for our personal experiences. The storing of such memories is usually affected by the person's affect during the incident. The stored memories also reflect rich affect about events. This is similar to recalling memories with friends while doing an activity. *Procedural memories* refer to the recollection of skills, particularly motor ones such as riding a bike or playing the piano.

The augmentation of the three types of memories is well-researched in the HCI community as it has numerous promising applications with the prevalence of pervasive technologies. For example, augmenting procedural memories using biofeedback facilitates skill acquisition in domains like sports and music (e.g. [143, 104]). The augmentation of semantic memories facilitates micro learning and monetizing memorable interactions such as advertisements and timelines (e.g. see [197, 69]). The augmentation of episodic memories facilitates reminiscence, reflection and helping individuals with memory impairments. However, the applications for the reformation of the memories is currently under-explored. In the upcoming sections, we will discuss both types of memory alterations. In this thesis, we mainly focus on designing MACS for altering episodic (see Chapters 6, 7, and 9) and semantic memories (see Chapter 8).

2.1.2 Remembering and Forgetting Memories

Memory cues are stimuli hints that trigger the recall of a past experience or of a future event[26]. They simply comprise any information snippet that helps us remember. Cues can be presented, for example, on peripheral displays throughout

the user's home or on users' personal devices, such as the smartphone. They are meant to trigger episodic and prospective memory recall. By frequently encountering certain cues, they can improve people's ability to recall a relevant memory and its details over time. Such effect could potentially persist without the need for further technological support. The selection of media type to present a memory cue can affect the remembering quality.

The term "remember" is a lay term that involves two types of retrieving information; *recognition* and *recall*. We use the term throughout the thesis to reference both types. *Recognition* refers to verifying a detail about an incident after seeing a clear cue about it or associating a cue directly with a past incident. An example is recognizing the face of a criminal in the suspects' line up. *Recall* refers to retrieving details that are not directly present in the available cue but are mentally associated with it. An example is seeing a generic red t-shirt while shopping then remembering that the spouse's favorite type of t-shirt is red and that they wore one to the first anniversary. The generic red t-shirt is not the same as the spouse's but the color and cut similarity trigger an older memory. In this thesis, we investigate both types of remembering while focusing on recall. The reason is that it is challenging to choose the presented cues within MACS, as designers need to limit the cues' density to avoid overwhelming users. Thus, it is more likely that recall is altered rather than recognition because of the details in the presented cues. We discuss later in Section 2.3 the motivation of people to seek to remember more about their lives.

There are two common types of memory failures: prospective memory failures and retrospective memory failures. Prospective memory failures are ones related to remembering to do future events such as going to a class in the evening or buying groceries. On the other hand, retrospective memory failures are ones related to past information about locations and people such as forgetting someone's name or job. We encourage the reader to check Eldridge et al.'s work [85] on the taxonomy of common memory problems in a work context for a detailed review of retrospective and prospective failures.

There are several theories about how people remember information. There are two particularly relevant ones that inspired our work in this thesis. We refer to these as (1) Tulving's theory [256] and (2) Loftus's theory [172]. The relevance is that they highlight a critical research problem; the selection of the captured and presented cues to alter memories.

1. **Tulving's theory [256]** Tulving explained how humans remember information using *the synergistic ecphory theory* which describes a "preconscious

process in which retrieval cues are brought in contact with stored information causing parts of that stored information to be reactivated" [256]. Cues could be visual (e.g., images), auditory (e.g., sound or speech), locations or mood [102]. Human memory is cue-driven by recognizing such stimuli rather than freely recalling them [231]. Gouveia and Karapanos [105] further suggested, based on Tulving's theory, that cues are of equal strength, but that more cues activate more parts of the episodic memory.

2. **Loftus's theory [172]** Loftus offered an alternative model in which we remember by reconstructing memories [172]. In this model, we only remember the key events within an incident, not all of the details. Every time we are required to remember the incident, we interpolate the details that logically makes sense to connect the stored key points. The interpolation relies on reasoning and contextual information rather than the objective truth. Thus, the so-called memory will only be partially correct as it can contain inaccurate details, and further, every time we try to remember the same event across the years, the deviation in the interpolation increases. This also explains how we start to forget the details then have completely altered versions of older events without objective evidence to fix them. An example is remembering an encounter with a colleague in the student volunteer party of a conference the person goes to every year. It is easy to confuse the year and location of the conference where the particular encounter happened. This is because the key points such as attending the conference, meeting the colleague, and attending the student volunteer party are similar in several editions of the conference. However, the person could narrow it down to two years because he/she recalled that the colleague had only attended those ones. However, the encounter may have happened in a third year that the person had forgotten about and had thus excluded the possibility.

The two theories focus on the remembering mechanisms, assuming the correct registration and storage of information during incidents. Alternatively, Schachter et al. [226] proposed a holistic model that identifies seven memory sins that happen during the entire information consumption pipeline. We already discussed these in Section 1.1, and categorize them here in a manner that resembles the building pipeline of MACS. There are two sins that affect the capturing and registration of information during an incident: absent-mindedness and bias. Another two sins affect the quality of stored memories: transience and suggestibility. Finally, there are three sins that affect the retrieval process of a required incident: blocking, misattribution, and persistence. Suggestibility for example can affect

eye witnesses in crimes through unintentionally merging details they saw in media in their testimonies. There are also existing examples of mass memory reformations, i.e. the “Mandela effect”, which refers to scenarios where masses believe a particular incident took place when it did not happen. An example is people believing Mandela died in prison in the 1980s when he actually died in 2013. Other interesting examples are found in [1].

2.2 Research Inspiration

In the following section a selection of research projects and groups are listed. This HCI research in memory alterations has impacted and inspired work presented in the thesis. It is not meant to offer a comprehensive review or discount the valuable endeavors of other research teams in advancing the design of MACS.

2.2.1 Memory Augmentation

The literature is highly focused around memory augmentation rather than memory reformation. *My Lifebits* offers a prototype for an external total-recall memory prosthetic. The successor project by another research team is *LifeLens*. *Quantified Self* focuses on selective capture to support behavioral change. *Memory Mesh* focuses on optimizing the search and selection of cues. *Recall* focuses on enhancing the inherent remembering without needing external interventions during the remembering situations.

1. **My Lifebits [11]** The project offers the first system that mimics total recall fulfilling the Memex vision[41]. The researchers in the project recorded and digitized everything in their daily lives including mementos and gifts, creating a massive indexable database of all the content and experimented with several types of (near)-continuous captures. One of the project leads, Gordon Bell, wrote a book reflecting on the social impact of the external memory prosthetic on his daily life in several domains such as work, productivity, health and more[29].

2. **Quantified Self (QS) [12]** This is a group of independent researchers, biological hackers, and early-adopters of technology who experimented with creating systems that enable individuals to measure their progress in different domains. Most of the systems are centered around health but those

are not the only contributions. They document their endeavors through a rich library of videos. We recommend the reader to check Choe et al.'s meta analysis of their contributions and motivations. [48].

3. **Memory Mesh and LifeLens [3, 274]** The work here bridges the gap between "My Lifebits" and "QS". One of the researchers, Cathal Gurrin, created a dataset of over fifteen million near-continuous photos. However, the main focus of these works is on creating algorithms to mine the information and infer behavioral patterns of the user. Both projects complement each other: one bridges the gap between information retrieval search techniques and cognitive psychology by focusing on features people remember to search for memories; the other focuses on creating a platform that captures, digitizes and presents one's life experiences. Our project could be considered the successor of the "My Lifebits" project.

4. **RECALL [13]** This research cluster aims at redesigning memory solutions to facilitate imparting knowledge, skill acquisition and memory enhancement without relying on external prostheses. An example is being able to remember phone calls rather than relying on the mobile phone to retrieve them. The project extensively explored near-continuous capturing systems as memory prostheses. For a sample of the cluster's endeavors, refer to this article: [64].

2.2.2 Memory Reformation

Literature about digital forgetting to support natural forgetting is more common than literature (1) investigating the adverse effects of the current technologies on deteriorating memories or (2) actively creating solutions to enable memory reformation. *ForgetIT* focuses on digital forgetting in work contexts. Sarah Clinch's group investigates the impact of technology on memory deterioration.

1. **ForgetIT [8]** The project focuses on digital forgetting in shared productivity contexts such as work. It uses managed forgetting and contextualized remembering to support efficient information retrieval from knowledge memory vaults. It targets two scenarios for optimizing the algorithms that decide on the forgetting and remembering: personal databases from events and organization databases documenting work expertise.

2. **Sarah Clinch's Research Group [7]** This research team focuses on investigating the adverse effects of using technology on deteriorating memories. They also look into multimodal interactions to augment the human memory.

3. **Materialising Memories [10]** This research team focuses on investigating every day practices for remembering, particularly remembering through forgetting. Their work also focuses on managing memories after negative experiences such as breakups and helping in materializing memories.

2.3 Memory Augmentation via Lifelogging

There have been several definitions for lifelogging since Steve Mann started using the term in the 1970s. Within this manuscript, we employ one of the recent *lifelogging* definitions by Gurrin et al. [112], that it is "a phenomenon whereby people can digitally record their own daily lives in varying amounts of detail, for a variety of purposes. It represents a comprehensive black box of a human's life activities and may offer the potential to mine or infer knowledge about how we live our lives". We also include within the scope of this thesis *life caching* as a subset of lifelogging practices. *Life caching* is a term coined by trendwatching.com referring to "collecting, storing and displaying one's entire life, for private use, or for friends, family, even the entire world to peruse"[40]. The combination of lifelogging and life caching can be seen on social media platforms nowadays. This motivates us to explore users' behaviors on social media as an example of a niche lifelogging application within a part of this thesis.

2.3.1 Benefits of Lifelogging

Niche memory aids such as reminders and calendars focus on supporting prospective rather than retrospective memory problems and are widely adopted and integrated into the user's routine. Chen and Jones [46] surveyed prior literature to identify user requirements for memory augmentation in daily life scenarios. They showed a need for circumventing retrospective memory problems using lifelogs because: (1) they are more commonly reported in prior work compared to prospective errors (e.g. [86]) and (2) users are more likely to benefit from a system covering them as they are aware that they happen and would ask the system for help, unlike prospective memory issues that require intelligent proactive systems. Additionally, lifelogs can circumvent forgetting resulting from encoding

problems [116]. Thus, a large number of works report on the benefits of existing lifelogging systems in augmenting the human cognition, specifically in the context of memory augmentation (see [228, 48, 116, 113] for examples). Example benefits include: supporting emotional growth, reflection and enhanced reasoning about past experiences, providing motivational cues to future actions (e.g. going to the gym), and supporting the recall of memories whether by providing cues to incidents (e.g. an old picture of a past trip with a friend) or by repetitively reviewing key incidents to better remember them. Thus, the projects in this thesis focus on supporting retrospective memories with only one exception aid targeting both prospective and retrospective memory problems (see Chapter 8).

2.3.2 Pictorial Lifelogs as Memory Prosthesis

Images promote more detail-rich recall than other types of data [142, 105] as they contain rich contextual information [158]. Specifically, episodic memories are sensitive to visual simulations [58, 116]. Thus, pictorial lifelogs have been extensively researched as a means to augment human memory (e.g., [73, 161, 227, 228, 112, 31]). We build upon this line of work and also focus on research explorations using pictorial lifelogs. Pictorial lifelogs could come from wearable cameras capturing the first-person perspective, excluding the lifelogger, or from infrastructure cameras capturing a third-person perspective, including the lifelogger. We refer to the latter type as *environmental lifelogging* (e.g. [162, 57]).

Pictorial lifelogs have been extensively investigated for helping patients with medical memory impairments (e.g. [203, 178, 204]) and for supporting the memory of laymen (e.g. [142, 174, 168]). Early studies on lifelogging like the pioneer SenseCam ones were centered around enhancing autobiographical memories through showing raw daily reviews (e.g. [130, 90, 227]). However, as the research progressed in the area, domain-based memory augmentation scenarios were developed (e.g. to motivate running [34], supporting education [28], facilitating work productivity [66], and food logging [173]). We encourage readers interested in in-depth reviews for lifelogging applications for adults to refer to the following meta reviews: Harvey et al. [116] summarizing the usage of lifelogs for memory augmentation, Choe et al. [48] summarizing the lifelogging benefits to enhance and support human behavior by analyzing the quantified self movement contributions, and Sellen et al. [228] for a critical review on applications of lifelogging for memory augmentation in real life. In this thesis, we focus on memory interventions for *healthy adults* for generic reflection on autobiographical memories. The current body of work focuses on generically

enhancing reminiscence rather than enhancing retrieval of specific forgotten information on demand when evaluating the memory augmentation benefits of lifelogging systems [116]. Thus, we explore both directions: generic recall and reminiscence (see Chapter 6) and answering specific questions about forgotten details (see Chapter 9).

2.3.3 Technical Lifelogging Frameworks

There is rich literature about how to technically build personal informatics systems and memory prostheses. The difference is that personal informatics systems primarily focus on reflection and the behavioral change while memory prostheses are a subset that focuses on altering memories for a variety of reasons such as reflection, behavioral change, trauma attenuation, and re-usage of past skills. We select four models from the literature to develop such systems: (1) Li's model [163], (2) Dingler's model [64], (3) Chen's model [46], and (4) Lee's model [160].

1. **Li's model [163]** Li et al. [163] presented a model for designing personal informatics systems that is composed of five stages: (1) motivation, where the user decides the reason for lifelogging and what to collect, (2) collection, where the actual data is gathered, (3) integration, where the raw data is transformed into information, (4) reflection, where the user relates the presented information to their behavior, and finally (5) action, where the behavioral change occurs.

2. **Dingler's model [64]** Dingler et al. [64] presented a model for designing a memory augmentation system. The model has three stages: (1) capturing of memory cues, which is similar to the second stage "collection" in Li's model, (2) extraction of memory cues, where the selection of a limited amount of cues happens to maximize the quality of memory enhancement, and (3) presentation of memory cues, where the user interacts with the selected cues.

3. **Chen's model [46]** Chen et al.'s model [46] was composed of three stages: (1) presentation of information similar to the third stage of Dingler's model, (2) capturing of data similar to Dingler's model first stage, and (3) retrieval of information referring to the curation and selection process of the cues similar to Dingler's model second stage.

4. **Lee's model [160]** Lee et al.'s model [160] is composed of three stages as well: (1) capturing the data, (2) processing the data, and (3) accessing the data. The stages also resemble Chen's model but the order is reversed.

Prior work has extensively explored the technical means to implement particular stages of pictorial lifelogging systems such as: capturing data (e.g. survey on capture methods in specific lifelogging cases [273], arousal-driven photo capturing [195, 222, 138], and capturing photos from the cornea [156]); storing data (e.g. [146, 47]); data segmentation and curation (e.g. passive recognition of activities [71, 42] and curation of summary reviews [158, 70]); searching for particular photos (e.g. interactive search engine [159] and semantic search [255, 262]); browsing and presenting photos (e.g. based on similarity [149] or generic browsing of lifelogs [72]); and standardized datasets to compare systems (e.g. NTCIR lifelog data set [111]). Rawassizadeh also proposed a holistic framework for lifelogging [208]. However, the focus was on the sensor fusion of various data sources, and the technological developments in each stage are beyond the scope of this thesis.Currently there is rich knowledge about different parts of lifelogging systems [116], however, there is no holistic workable model to follow to create such systems [116]. This thesis bridges this gap by building upon the aforementioned models' work and introducing a four-staged design framework to build MACS (see Chapter 3).

2.4 Memory Reformation Applications

In this section, we shed light on the relatively recent growing research domain of memory reformation resulting from the interaction with ubiquitous technologies. It is worth noting that this domain offers rich research opportunities and is not as well-explored as the applications for memory augmentation. This could be attributed to three reasons: (1) the wide market penetration of niche MACS such as social media is relatively recent, therefore so are the unfolding repercussions of extensive usage, (2) the ethical challenges in conducting such studies as they usually require a level of user deception to clearly detect the reformation [53, 260], and (3) the challenge of defining cognitive metrics for forgetting in real-world scenarios while isolating the impact of other confounding variables [53]. Similar to our approach for categorizing MACS, Clinch et al. [53] proposed two distinct use cases for examining the impact of technology on the memory: (1) systems that accidentally cause the memory degradation and (2) systems that deliberately alter it. We review below some of the prominent research trends for each type

and provide some examples that are not meant to be comprehensive but rather a starting point for interested readers. We encourage the reader to check [54] for a meta reflection on technology-mediated memory impairment.

2.4.1 Accidental Memory Reformation

This area is where the majority of the research in the domain is currently happening. For example, Baron et al. [27] investigated the impact of using the Internet and GPS on decreasing the quality of memories. They found that GPS usage is associated with decreased abilities of unaided physical navigation. Sparrow et al. also showed that now we tend to externalize our memories where we have lower recall of raw knowledge but better recall of where to find what we need [237]. We focus on *two prominent research directions* with growing bodies of work:

1. **Impact of social media usage on the memory degradation** Sharifian et al. [229] showed in a recent study conducted with 782 participants that extensive social media usage is associated with negative affect that results in poorly recalling events from the days of heavy usage. Similarly, Tamir et al. [250] showed that being involved in documenting real events via social media while they happen to preserve them degrades the participants' memories of such events. Wong et al. [267] showed that posting photos about an event can crystallize memories about the event in the photo while enhancing the recall of the photo and the event in it. This is because of retrieval induced forgetting of other relevant events not covered in the photo.

2. **Impact of photography and photo reviewing on the memory degradation** The degradation from photography has been mainly but not only studied in the context of social media and cuing of eye witnesses. Prior work shows that unlimited photo captures might be degrading the encoding quality of memories in what is known as "photo-taking impairment effect", as users treat it as an "external brain dump" (e.g. [235, 194]). Adams et al. [16] also showed an interestingly dangerous reformation effect from reviewing photos taken by a chest-mounted camera to enhance the recall quality of eye witnesses. They showed that participants removed true details of the incident from their initial statements when they did not find evidence for it in their captured photos. This shows that the users' trust in the correctness of the system can facilitate malicious memory implantations. This phenomenon was also discussed in [68, 53, 260]. Jones et al. [139]

offered another perspective on the problem by showing that participants do not interpret data from body-worn cameras objectively. In their controlled experiment, they showed that misinformation given by a police officer was still reported in participants' statements even if it contradicted information in their body-worn camera footage.

These two research directions inspired the work in this thesis, as our research projects focus on pictorial representations from lifelogs and investigates user behavior on Facebook as an example of a niche MACS.

2.4.2 Deliberate Memory Reformation

This area has been less investigated in literature outside professional academic contexts. The literature we found usually focuses on psychological techniques for a specific use case rather than ubiquitous interventions for niche usage. We observed a research trend for ubiquitous interventions related to *forgetting after loss*. For example, Herron et al. [126, 125] discuss the complexity of disposing of digital possessions after breakups to facilitate forgetting and moving on. Some participants for example waited to get a new phone to lose older chats, while others started by deleting all digital history as it was hard to look at it and reminiscence over it. We consider this a form of deliberate memory attenuation in the age of social media [126]. Similarly, Sas et al.[223] found that retaining digital possessions post breakups is likely to be provocative and upsetting. Works about intentional forgetting by disposing possessions often refer to three user groups: (1) keepers, that keep all possessions, (2) deleters, that eliminate all possessions, and (3) selective disposers, that exhibit a hybrid behavior of the other two groups [223, 126]. Well-designed MACS could particularly help in such scenarios as time, distance and emotions highly influencing the deletion strategy [223]. An example is hiding content rather than deleting it for selective disposers for specific periods of time to maintain the records for potential future reflection while reducing the emotional pain right after a breakup.

We also observed two research trends/use cases for psychological interventions that we think would benefit from digitization and building relevant MACS:

1. **Psychiatric Therapy** There is a body of work about helping patients with Post Traumatic Stress Disorder (PTSD) by attenuating their memories. The attenuation can happen by suppressing parts of the memory or gradually rewiring and re-framing parts of it to change how patients remember it. For

example, Gray et al.[106] introduced a new method called Reconsolidation of Traumatic Memories (RTM), which is used to reduce the severity of symptoms for patients with PTSD after five hours of treatment. In RTM, patients experience short videos of their traumatic events in safe places and re-narrate what happened. The researchers aimed in their study to alter key aspects of the problematic memory such as color, clarity, duration and perspective. Such a system has the potential for digitization and providing a biofeedback loop, for example, to support therapists in the session. Another approach is neural damping of neurons responsible for the troubling memory to attenuate fear memories [145]. One could imagine building ubiquitous systems to aid with this task. Another idea presented by Kalbe et al. [141] is the attenuation of memories in stressful situations by informing users prior to the situation about the encountered stress. This technique works because stressful situations are more likely to be remembered. Informing users about upcoming details reduces stress which consequently reforms the way we store the memory. Future MACS could possibly aid by detecting and deriving patterns from past behaviors and informing users about them prior to predicted situations.

2. **Optimizing Advertisements and Altering Collective Memories via Fake News** There is a large body of work on increasing the memorability of advertisements. However, there is also some work done on deliberately influencing people to forget about certain products or alter their impressions of certain individuals / products. For example, Shen et al. [230] conducted a study where they intentionally cued participants to remember or forget specific advertisements. Interestingly, they investigated the complexity of deleting information when it was presented creatively despite deliberate forgetting techniques used. Their work is an example for dissecting system design parameters to provide recommendations for memory alterations. Another elaborate example is the work done by Sherman et al.[232] to implant false memories about competitor brands using television advertisements in real setups. They used the Deese–Roediger–McDermott (DRM) psychological paradigm which basically describes the tendency of participants to recall a relevant but absent item from a presented list of items. For example, the researcher presents five fruits and the participant recalls a sixth absent one. They also showed that the participants are confident and elaborately remember the false memories. There is an open opportunity for designing directed advertisement delivery using ubiquitous technologies and utilizing participants' memories to promote buying particular products [62].

2.4.3 Reflection on the Research Trends

There is a growing body of work examining accidental degradation because of ubiquitous technologies unlike deliberate ones. This might be attributed to the aforementioned ethical challenge in conducting the studies as well as the fear of malicious usage and unclear use cases. Systems targeting deliberate reformations are mostly focused around "the right to be forgotten" from a digital privacy-protection perspective rather than memory-alteration perspective. There is a current research gap though in: (1) isolating and understanding the system design parameters that affect the reformation, (2) how to deliberately use such parameters for targeted reformations, and (3) how to design such parameters to avoid accidental reformations. The work in this thesis is one step forward in this direction by offering a framework of parameters to design MACS (see Chapter 3) that shall facilitate future investigations to dissect design recommendations for each parameter for memory alterations. Through one of our projects (see Chapter 9), we show the impact of potential memory reformation using lifelogs.

2.5 Technologies Aiding Memory Alteration

In this section, we present a concise overview about technologies we use in our upcoming research projects. We use BCIs for one project and pervasive displays for the others.

2.5.1 Brain-Computer Interfaces

In this section, we briefly discuss Electroencephalogram (EEG)-based BCIs. We use BCIs to capture memory cues or as a cue of mental states such as indicators of remembering or forgetting of memories. BCIs have been used to detect an audience's real-time cognitive engagement implicitly. For example, they were used during a performance art show to offer guidelines for designing theatre performance [270], in viewing museum exhibitions to design and customize museum experiences to each visitor's taste [14], and while listening to presentations to help presenters improve their performance real-time or post-hoc [120]. Cognitive engagement has also been detected and visualized at work [118] and in learning [23, 24, 135, 177, 245] to give a user self-reflections to improve motivation and engagement. Alpha waves sensed by BCIs have been used as a monitoring tool for mindfulness meditation training and behavior change activities [241].

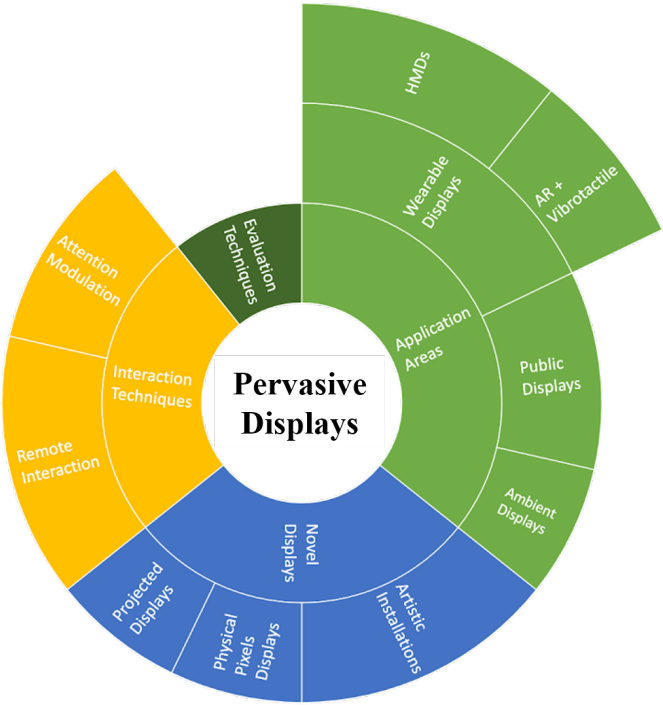

Figure 2.1: Summary of the research trends in the domain of pervasive displays

We build upon this body of work by using alpha waves as an indicator for mental engagement and using mental engagement as a proxy for an *occupied mind* thinking about memories. We envision a symbiotic relation between two participants in an artistic setup where they share abstract proxies of thinking about their memories (see Chapter 7).

2.5.2 Pervasive Displays

Pervasive displays are displays found everywhere in the user's environment and embedded in their daily interactions. We discuss them as an example technology frequently used in MACS for presenting memory cues to alter memories. We offer a generic overview of the domain by presenting a structure for the common contributions via analyzing the submissions of a specialized conference, namely "The International Symposium on Pervasive Displays" (see [**?**]). Figure 2.1

summarizes an excerpt of the research directions for pervasive displays. Our analysis showed interest in creating applications for existing pervasive displays, particularly the wearable displays such as Augmented Reality (AR) and VR goggles. There is also interest in building novel displays such as levitating particles (e.g. [96]) and plant-based displays (e.g. [100]). We grouped the research into four categories:

1. **Application Areas** This category focuses on building applications for existing technologies. Most of the contributions were towards developing wearable displays, particularly Head Mounted Displays (HMDs), then AR and vibro-tactile displays. The other interesting types of displays was public displays followed by ambient displays.

2. **Novel Displays** This category focuses on building unconventional types of displays to push the limits of methods to convey information. Most of the contributions in this category were in the form of artistic installations. There was also a growing interest in building physical pixel displays such as the levitating particles and the plant-based ones. There were also contributions related to projected displays.

3. **Interaction Techniques** This category included research contributions related to attention modulation of the user to facilitate information consumption and creating novel remote interactions with the displays.

4. **Evaluation Techniques** The last category focused on creating techniques to evaluate existing solutions.

The remainder of this section focuses on contributions towards 2D large displays and projections (shortly referred to as large displays) in public and private contexts to set the research context for the upcoming research projects in the thesis (see Chapters 6,7, and 8). We recommend the reader to see [52] for an overview of the development history of 2D large displays.

Clinch et al. [52] predicted that there will be constant access to peripheral digital information in the near future via pervasive displays. Large displays can aid in recall, enhance presence, support enjoyment, and increase attention and arousal [221]. Wall displays showing overviews of information can support spatial memory, which enhances productivity [137]. The large space of the screen offers better immersive interaction opportunities to see details in graphical content such as photos and videos. Additionally, it enhances the number of visual discoveries

and supports integrative holistic insights about the presented data [210, 22]. Thus, they are a popular medium for presenting memory cues for memory alterations.

They have been widely used in a plethora of applications for memory augmentation. Ambient augmentation examples include learning and advertisement scenarios (e.g. [184, 20, 220]). Active augmentation examples include supporting dementia patients and reflection on lifelogging datasets (e.g. [221, 144]). For example, Kelly et al. designed an installation called "Color of Life"[4]. In this installation, they show a square for each lifelogging photo filled with the most dominant color in the photo. It is an abstract indirect proxy to the dominant colors in one's life referring to the common types of activities in their days. This installation inspired our design for one of our prototypes "Life-Dome" discussed in Chapter 6. We continue this line of work by creating a prototype for domestic reflection over personal memories. In contrast to the "Color of Life" installation, our system shows the real lifelogging datasets leveraging the users' natural cognitive filtration via the color salience to support reflection and search in larger pictorial datasets.

There was no difference in recall quality of large screen content when introducing voice or touch interactions or eliminating them [198]. Additionally, excessive movement can negatively impact the recall quality [200]. Thus, we used such principles and limited interaction and mobility in our prototypes.

A design challenge in curating content for large displays is the granularity of the presented data to balance between "calm computing" and efficiently delivering information [52]. This is particularly seen with the heterogeneous wide user base with varying needs in the context of public displays [52]. Additionally, the attention span of the users to the screen content is decreasing, causing what is called "display blindness" where users no longer pay attention to the changes on the screen [60, 191]. To this end, we chose to experiment with content curation and selection as they are key tasks for designing MACS in the context of public displays in a university campus. We wanted to use the content on the public display as a use case for ambient memory augmentation.

We chose this context as there is a rich literature showing the benefits of public displays in university campuses to support learning and togetherness (e.g. see [242, 182, 184]). Mikusz et al. [184] showed that the movement patterns of students are predictable and could be used to optimize the delivery of memory cues to leverage a memory-altering system (they referred to augmentation in their context). Prior work shows that common public spaces (such as university grounds and communal areas) can give a sense of belonging to the newer members of the community [45]. Carefully designing content that allows new members

to know more about the existing members of a community can give a sense of closeness and familiarity in a process called "social triangulation" [49, 182, 252]. Memarovic et al. widely explored this line of work by looking into design methods for content promoting communication on public displays in university setups (e.g. see [180, 179, 182, 181]). For example, they showed that mere installation of a public display showing relevant content to the students can support a stronger sense of awareness about the group [182]. They also showed that upcoming scientific events, class relevant material, recreational news, personal class project info, upcoming cultural events, and scientific news are among the most requested types of content on public displays for campuses [182]. However, they acknowledged that there is a need for personalizing content for students and better understanding their needs. We extend this line of work by investigating the content curation process from the perspective of several user groups: new students, enrolled students, and academics. Our goal is to investigate the design process of an ambient MACS that enhances the sense of familiarity and belonging of the students to their campus (see Chapter 8).

2.6 Privacy of Captured Pictorial Cues

The continuous capture of pictorial lifelogs poses a significant challenge for the protection of the privacy of bystanders and possibly the lifelogger (in case of environmental lifelogging). Privacy infringements could happen through human consumption (others seeing private or uncomfortable content) or via computer vision attacks. This work focuses on the former, i.e. *infringements from human consumption*. The privacy of bystanders is primarily protected by social conventions allowing them to opt out of the wearable capturing space [91]. However, this is often a challenging task for the lifelogger to remember to disable their capturing device or to search for the violation after it happens. Hoyle et al. showed that lifeloggers are willing to apply propriety preferences to discard or modify photos infringing on the bystander's privacy if the detection of bystanders is automated [133].

Protection methods include: physically marking objects that should not be captured [215], automated activation of personalized capturing policies in specific contexts [17, 239, 253], automatic or manual deletion of content upon detecting certain cues [153], and obfuscating parts of the photos [153, 166, 167].

In this thesis, we look at two types of privacy protection (see Chapter 9): (1) deletion upon detecting certain cues and (2) the partial obfuscation of photos to

hide certain cues. We chose these as they are most commonly used in literature and practice. Obfuscation is "the production of noise modeled on an existing signal in order to make a collection of data more ambiguous, confusing, harder to exploit, more difficult to act on, and therefore less valuable" [38]. Prior research studied obfuscation of sensitive elements in photos including screens [153], objects [117]) and people [254, 167]). We study the obfuscation of people as they are among the most salient memory cues in photos [158]. Previous work showed that face and body are among the photo parts that are perceived to be sensitive [164]. Thus, obfuscating individuals is done by obfuscating the *face*, where only the head is distorted (e.g., in Google street view), or obfuscating the *body*, where the body and face are distorted [167]. Prior work also showed that cropping bystanders reduces privacy risks while preserving the rest of the image content [254], at the expense of aesthetics. Li et al. evaluated multiple obfuscation methods for face and body. They recommended inpainting individuals or replacing them with avatars because these obfuscation methods provided a good trade-off between effective protection of privacy against computer vision attacks and a good viewer experience [167]. However, they also reported that blurring was among the preferred techniques, conforming with its extensive usage in research and practice [32, 136, 166]. Gross et al. showed that blurring and pixelating of human faces could extensively expose features hindering privacy, or extensively eliminate features hindering the utility of videos [109]. Therefore, we employ body obfuscation in our research project as an example for obfuscation methods because Li et al. found that body obfuscation is more effective against human recognition than face obfuscation only [167]. Additionally, we chose it to maintain the likability and social acceptance of lifelogs as personal mementos.

2.7 Sharing in MACS

We start this section by describing parameters we identified through our projects to understand the sharing of memories in MACS. Afterwards, we reflect on sharing patterns in social media. We choose social media as a niche example of MACS.

2.7.1 Parameters Affecting Sharing Memories

The following parameters are identified from our experiences designing the research projects presented in the subsequent chapters. We present them now for the

reader to build a mental model for evaluating sharing practices and stakeholders in MACS.

1. **Bystanders** Memories are human captures of life events. *Individual memories* refer to events happening to the person alone without witnesses. *Witnessed memories* refer to events that have bystanders or contributors. Bystanders are passive witnesses like people in a street seeing a person fall. Contributors are others who are part of the event, like people who would help the person who fell. Individual memories are harder to objectively verify without ubiquitous interventions.

2. **Perspective** *Personal memories* are memories as recalled by an individual even if they happened in a group. *Group memories* are the collective details remembered about an incident by a group of people. Personal memories and group memories might not align about the same incident. For example, the temporal order of events in a birthday party might be mistakenly confused by a person and corrected by others in the same party.

3. **Sharing Context** Memories and their respective narratives could be kept *private* (i.e. with the individuals who experienced the real events). Alternatively, they could be shared within small groups, i.e. in a *semi-public context*. The groups could have experienced the memory with the user or only knowing it from the user's perspective. Alternatively, they could be *shared publicly*. Wide sharing provides a chance for scrutiny in verifying the details of a memory. However, it poses a privacy and security challenge of re-using / re-framing the memory content against a person.

4. **Narrative** *Emotional narrative* refers to recalling the emotions associated with a particular event and it is more subjective. Thus, it is harder to verify through memory capturing techniques. *Procedural narrative* refers to recalling the details of the event itself and it is more objective. Thus, it is easier to verify through memory capturing techniques. For example, a birthday procedural narrative could be that the cake was served then I blew out the candles and everyone congratulated me. This could be verified from the cake video. The emotional narrative could be "I felt excited to start a new year but was sad that my parents were not attending my birthday". This is harder to verify from the video as the person is smiling and maintaining a happy demeanor out of politeness.

2.7.2 Sharing on Social Media

Social media is a modern niche form of MACS (see [218] for an example application). Users share selective snippets of events and interests to curate a digital archive of their lives. It is estimated that 49% of the world population currently uses social media, which is equivalent to 4.15 billion mobile users world wide, with Facebook being the most commonly used platform [251]. The wide proliferation offers a unique opportunity for understanding users' perspective on privacy and preferences of sharing their memories with other users and/or smart platforms to fuel intelligent personalized interactions. Looking at such patterns gives us a glimpse of future patterns for current research technologies such as lifelogging. Thus, we use Facebook as an example platform in our research projects.

There are several theories about reasons for sharing on social media (see [197] for a concise review). Talking about oneself is a rewarding task that helps in self representation [249]. Social platforms like Facebook temporally control the reporting of gratifications such as "likes" to maximize engagement [197]. Using the bias to remember wins, longer episodes of usage could be resembled to gambling behavior [197]. Online support groups are often used to support people during difficult life transitions [114] such as losing people for breakups or death [261, 214, 127], scientific and career transitions [89, 154], sickness [25, 243], and mental health struggles [39, 36]. Thus, users of support groups are considered from the vulnerable and marginalized populations. The social norms and expectations depend on the online community rather than the offline community. Thus, users are often required to change their online personas to fit in and avoid alienation [188]. Failing to conform to norms of the virtual space can lead to negative social repercussions from other group members. This is particularly relevant while sharing about socially sensitive issues such as sexual harassment [217]. The repercussions can vary from online ones such as bullying and hate speech to offline ones such as public defamation. For example, Phadke et al. [202] showed that the diversity in content on Facebook enables hate groups to efficiently recruit and radicalize other users into their ideologies. This dynamic might have contributed the the "finsta" phenomenon. This refers to the creation of fake secondary accounts on the social platforms that are hidden from family and friends to escape the social pressure [269]. However, the fake accounts usually involve less desirable social traits associated with bullying behavior [247].

The negative repercussions of sharing are maximized when the users do not understand how their data is being used on the platform and/or who can see and interact with it. For example, users found accurate automated personality analysis from their social media interactions "creepy" and they felt helpless as

they had the urge to share it but did not like this aspect [264]. Prior work has also found that the majority of users are unaware about the implications of their privacy settings [15, 171]. For example, Mondal et al. [189] found that residual activities with withdrawn content such as tweets responding to a deleted tweet could still efficiently enable users to reconstruct the deleted content or even identify characteristics of fully deleted accounts. This implies that they do not fully control who sees their content in semi-public interactions such as support groups nor that they are aware about how their data is used to build personalized interactions. Similarly, Eslami et al.[88] found that over half of the users were unaware that the Facebook news feed is algorithmically curated. Hsu et al. [134] found that half of their participants randomly set their privacy settings despite having a need to set it correctly because: (1) they either did not understand it or (2) were not aware it exists, particularly ones related to advertisement personalization. We extend this body of work by looking into: (1) the sharing patterns for a specific type of online support groups, that is women-only Facebook groups in the MENA region, and (2) surprising interactions on Facebook and their impact on the user experience of the platform (see Chapter 10).

2.8 Summary

In this chapter, we present the context of our research highlighting how we built our work on the valuable contributions of fellow researchers showing the need to consolidate the design process of MACS. We started by introducing the psychological background for remembering and forgetting of memories. We particularly focused on Schachter's "sins" explaining forgetting [226], Tulving's theory about cued recall [256], and Loftus's theory about forgetting as a result of skewed memory reconstruction from key nodes [172]. The three theories explain the psychological basis of our research projects' interventions. Afterwards, we curated research clusters working on memory alterations. Next, we showed the benefits of lifelogging for memory augmentation such as reflection, behavioral change, and emotional growth. This is particularly true for retrospective memories which is why we target altering them for healthy adults in most of our upcoming research projects in this thesis. We also motivated our focus on pictorial lifelogs specifically as they showed promising results in actively jogging the memories. Afterwards, we introduced an overview of existing technical lifelogging frameworks [163, 64, 46, 160] to show how we built our framework on top of them. Afterwards, we covered some of the research efforts to build ubiquitous interventions for memory reformations. We highlighted research

trends in accidental memory reformation to investigate the impact of social media and the impact of photos on memory degradation. Afterwards, we highlighted that work investigating deliberate memory reformations is scarce compared to accidental reformation. We discussed three research trends: forgetting after loss of individuals, forgetting as a tool for psychiatric therapy, and optimization of advertisements and spreading of fake news. We pinpointed a research gap in identifying parameters causing memory reformation in MACS and motivated our upcoming proposal of a parametric framework to facilitate targeting and understanding the impact of particular design parameters on memory alterations. Afterwards, we reviewed two technologies we used in our projects for memory alterations: brain-computer interfaces and pervasive displays, particularly in the context of ambient memory augmentation in university campuses. Following the same structure, we reviewed common methods for protecting the privacy of individuals in captured photos as most of our research projects involve photo captures. Body obfuscation was the most commonly used, thus, we investigated its impact on the quality of memories in a research project. In the last part, we offered the following set of parameters to think about the stakeholders and sharing practices in MACS: bystanders, perspective, context, and narrative. Afterwards, we reflected on common sharing practices in online support groups on social media, as social media is a form of niche widely-used MACS. We show that users are usually not aware of the reachability of their shared content despite the grave social consequences resulting from uninformed sharing, which motivates us to investigate this in two upcoming projects.

II

Framework Design

Chapter 3

MACS Framework Design

This chapter is the foundation for discussing our research for the remainder of this manuscript. It summarizes our experience in designing projects for memory alterations as well as synthesizes our knowledge about existing literature of designing memory altering systems. The outcome is a framework to systematically tackle focal points to design the the systems (see Figure 3.1). It is divided into three parts. The first part highlights the three psychological goals for memory alterations, i.e. the motivation for designing the ubiquitous systems. The second

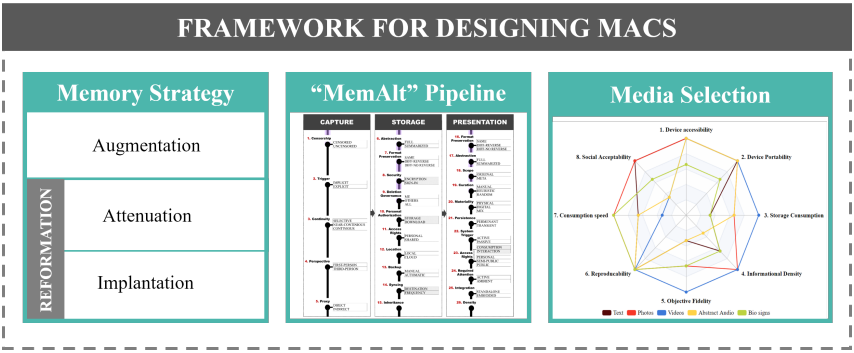

Figure 3.1: Overview on the 3-part framework for designing MACS. Part 1 targets the strategy for memory altering. Part 2 is a technical pipeline for building MACS. Part 3 is a set of parameters for selecting media to represent memory cues.

part discusses a Memory Alteration Pipeline (MemAlt) for designing new systems and reflecting and comparing existing ones. This framework is the aggregation of our knowledge about the domain. The third part discusses selection criteria for media to represent memory cues and reflects on the types used in this work. The three parts combined offer a holistic outlook on ubiquitous memory interventions.

Parts of this chapter are based on the following publication(s):

P. Elagroudy, S. S. Feger, and A. Schmidt. A model for selecting media type of memory cues in ubiquitous prostheses. In *AHs 2022: Augmented Humans 2022, Hybrid Event / Munich, Germany, March 13 - 15, 2022*, pages 313–316. ACM, 2022

3.1 Strategies for Memory Alterations

In this section, we focus on three changes that could happen to memories via technological interventions: *memory augmentation*, *memory attenuation*, and *memory implantation*. In Chapter 4, we will map our research projects to those types. We use the verb "remember" in this section to represent recognition and/or recall. We use the following common scenario to highlight the difference between the three cases:

Scenario context: There are five friends: John, Emilia, Rafael, Passant, and Nada. John went to Emilia's birthday party last month then to Rafael's party this month. Passant went only to Emilia's party. Nada did not attend either party. Each party took place in a different public park on a sunny day. Emilia's party had ten attendees while Rafael's had fifteen. Three common friends attended both parties. Nada asks John who attended Emilia's party and to describe the setting while blowing the candles. Without memory aids, John mentions the names of six attendees and that the weather was sunny.

3.1.1 Memory Augmentation

Memory augmentation refers to increasing the quantity and/or quality of details remembered about an incident. Additionally, indirect cuing of events using the

cues from another event is also considered memory augmentation. This can imply remembering forgotten details or correcting misassociated ones. It also refers to meta analysis of several memories to reach holistic findings and understandings for incidents.

This is the most common goal for memory aids in the literature. It combats the natural forgetting mechanisms providing further evidence for individuals to better understand their experiences and enhance their judgment. Reasons for the augmentation include: compensating for medical forgetting such as in the case of dementia patients, saving effort by re-using older experiences and content such as using document templates, providing a better informed outlook on incidents that shape our reactions towards others and the environment, augmenting skill acquisition by building upon older experiences, supporting reminiscence, and supporting goal tracking and self-motivation. Sections 2.2.1 and 2.3 offer some literature insights.

> John sees two photos in the mobile gallery showing a group of people singing. One photo belongs to Emilia's birthday while the other belongs to Rafael's birthday.
> Increasing the quantity of details would be remembering another two attendees because their faces show in the photos and realizing there were balloons and pets around (recalling forgotten details). Increasing quality of details would be realizing after the group photo that one of the originally recalled six attendees was not actually present. Meta findings could be John's realization that he always looks nervous in group photos. This was not apparent until he saw both group photos from different events.

3.1.2 Memory Attenuation

This refers to decreasing the quantity and/or quality of remembered details about an incident. This is mainly about forgetting of details. It also refers to complete blocking of particular incidents.

Literature creating deliberate interventions to attenuate memories is relatively scarcer than that focusing on augmentation. This is primarily because of the ethical dilemma about the implications of blocking or erasing memories on the behavior of people. It is also because of the challenge in selectively choosing memories to attenuate. For example, the movie "The eternal sunshine of the

spotless mind" artistically discussed the challenge that if we are able to selectively delete memories with partners after breakups, would that make us prone to making the same mistakes again and falling for the same person? However, there are research explorations into "digital forgetting" to allow natural forgetting mechanisms to take place in cases of trauma. Example use cases include the role of digital services in aiding with grief over deceased figures (e.g. [224]) and digital interactions after breakup (e.g. [128]). We recommend checking ForgetIT EU project [8] as an initial proxy for recent work in the domain.

> All morning photos were taken by the mobile phone of one person and they subsequently deleted them. Passant is privacy-aware and requested the deletion of all photos including her face from Emilia's birthday. A couple of months after the birthdays, John checks his social social media for photos as a memory aid and all the photos are at night without Passant.
> Decreasing the quantity of recalled details would be forgetting that Passant attended the Emilia's birthday. Decreasing the quality of recalled details would be forgetting whether the birthday started in the morning or at night. Blocking incidents could happen if no one shared any photos on social media about Rafael's birthday, and when someone spoke about that birthday years later, John might not recall that he had attended it.

3.1.3 Memory Implantation

This is a variation of memory attenuation. It refers to remembering fake details about a particular incident. The remembered details could either be completely deduced and unfounded, or misassociated from another similar incident.

Literature around memory implementation as a primary goal for ubiquitous systems is scarce. However, it is often studied as an undesirable side effect. For example, there is rich psychology literature about the negative impact of leading questions or public news on eye witnesses in falsifying witnessed details (e.g. [265]). Art also depicts malicious use cases such as using implanted memories in torturing scenarios. However, we envision positive use cases for memory implantation in professional setups such as handling painful memories for patients with post-traumatic stress disorder. We also encourage system designers to investigate the impact of their solutions on implanting memories as they can be an accidental side effect to regular designs (e.g. [**?**]).

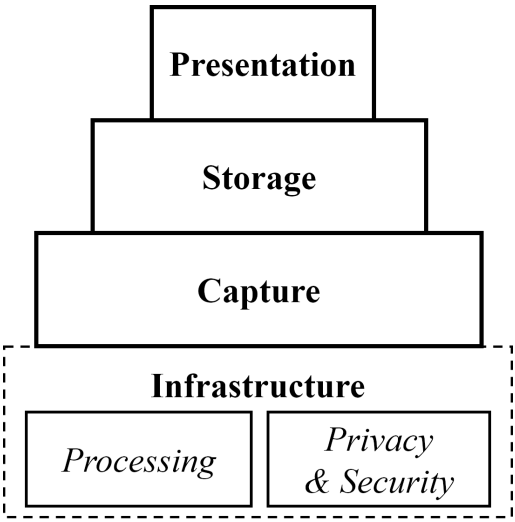

Figure 3.2: We propose a technical pipeline named "MemAlt" for designing MACS. It is composed of four layers inspired by existing literature. The memory cues are collected in the *capture* layer, banked in the *storage* layer, then shown to the user in the *presentation* layer. At each layer, the data is processed and protected, forming the *infrastructure* layer.

> John sees a picture from Rafael's birthday party of a lady with long curly hair with her back facing the camera. Passant has a similar appearance. However, Passant only attended Emilia's party. Misassociation would be John thinking after this photo that Passant had attended Rafael's party because of the accidental similar photo setup.

3.2 MemAlt: Memory Alteration Pipeline

This section is considered the foundation for the remainder of this thesis. We introduce *MemAlt*, a framework for designing ubiquitous systems for memory alterations. The work presented in this part aggregates our knowledge about the design process from building the projects as well as abstracting parameters from similar projects in related work. The framework serves two purposes:

1. **A design tool**: a checklist for designers building systems from scratch highlighting crucial design points.
2. **A reflection tool**: a basis for meta comparison of different systems as well as aggregating findings about a project.

To showcase both purposes, we discuss in the upcoming chapters four use cases for memory alterations. For each use case, we use the framework to highlight the design decisions in the beginning then re-use it to showcase what we learnt from the system at the end. The four projects serve as an example for using the framework as a design tool.

The framework is presented as a pipeline of four layers: infrastructure, capture, storage and presentation (see Figure 3.2). The *infrastructure* layer provides common algorithmic services used in the other three specialized layers. The services focus on processing, privacy and security protection. The *capture* layer focuses on the collection of the memory cues. The *storage* layer focuses on the treasury of the collected data. Finally, the *presentation* layer focuses on the display of the memory cues. We discuss each layer in detail in the upcoming sections and dissect it to a list of design parameters and possible values for each parameter. Figure 3.3 provides an overview of all the parameters.

3.2.1 Infrastructure Layer

This layer represents overarching services used repetitively across the three main stages of the pipeline to design memory-altering systems (i.e. capture, storage, and presentation). It covers two sub-layers: *privacy and security* and *processing*. Actions of the sub-layers can happen before and/or after each of the three stages depending on the memory alteration use case. The spectrum of design decisions in this layer is diverse and highly dependent on the constraints of the three stages. Thus, they are not the main focus of this thesis and are explored as a byproduct for designing the memory altering systems.

Processing layer refers to algorithms for data manipulation to optimize design decisions in the three stages. Common reasons for requiring a processing layer include: protecting the privacy of the user and the bystanders, saving storage space, adding a logic layer to discover more insights in the data, and optimizing the presented content to the user. Within the scope of this thesis, we covered three scenarios:

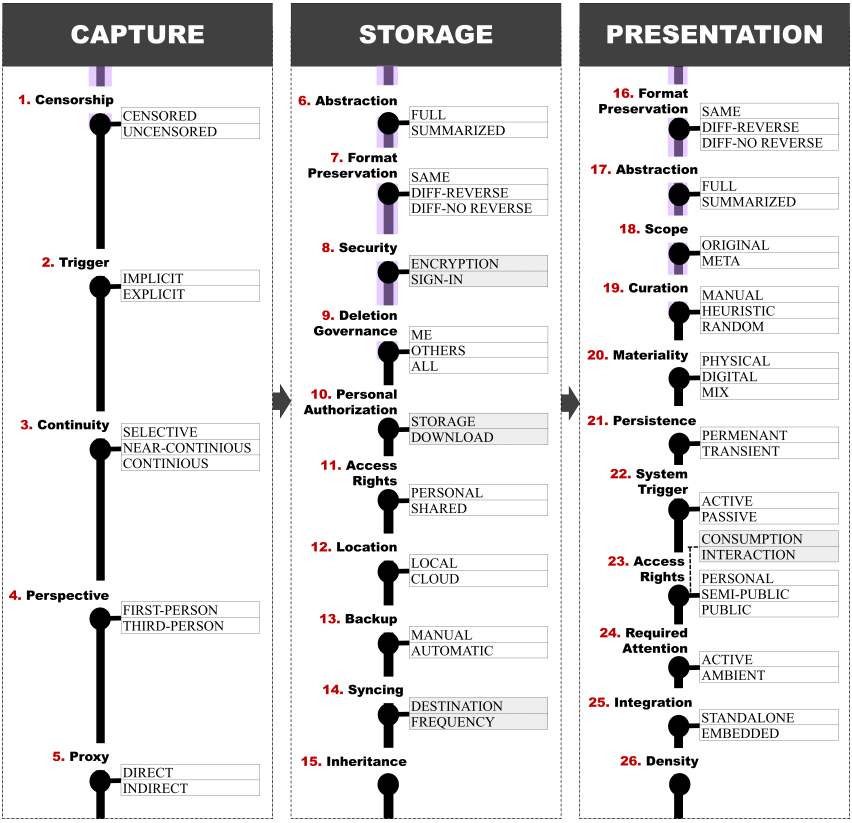

Figure 3.3: Summary of the parameters of the "MemAlt" framework. The red numbers are parameter IDs that will be used for the remainder of this manuscript. White boxes represent possible values for a parameter. Shaded boxes represent a flexible design aspect. The purple line highlights the processing parameters within each layer.

1. Processing post-capturing to protect the privacy of the user.
   (**PPMCloak** project covered in Chapter 9)

2. Processing pre-storage to minimize the used space.
   (**LifeRewinder** project covered in Chapter 6 and **SpotlessMind** project covered in Chapter 7)

3. Processing pre-presentation to browse large datasets.
   (**RDT** project covered in Chapter 6)

Privacy and security sub-layer refers to algorithms for data protection from a system perspective (security) and algorithms concealing sensitive user data for privacy protection. Common reasons for requiring a privacy and security layer include: removing confidential information about the user from the captured cues, removing sensitive information about bystanders, protecting the data from malicious attacks and unauthorized remote usage, and adhering to regional data protection laws covering remote storage and usage of user data. The implemented actions in this layer use the logic built in the processing layer. Within the scope of this thesis, we covered two scenarios:

1. Processing post-capturing to protect the privacy of the user.
   (**PPMCloak** project covered in Chapter 9).

2. Processing pre-storage for encryption to enhance the system security.
   (**RDT** project covered in Chapter 6)

The design parameters for the infrastructure layer are highly integrated into the design parameters of the three specialized layers (capture, storage and presentation). Thus, we enlist below the IDs of parameters belonging to both sub-layers and introduce them in detail with their respective specialized layer.

- Processing parameters are: *1. censorship*, *6. abstraction*, *7. format preservation*, *8. security*, *9. deletion governance*, *16. format preservation*, *17. abstraction*, *18. scope*, and *19. curation*.

- Privacy and security parameters are: all parameters could result in privacy and/or security violations. Thus, system designers should consider the privacy and security constraints for each design decision.

3.2.2 Capture Layer

In this section, we discuss the parameters for designing systems capturing memory cues. We present the definition of five parameters, list possible options for each parameter, and provide an example use case for them.

1. Censorship This refers to automated capturing interruptions to protect the user's privacy and security while collecting large amounts of cues. *Censored capture* value refers to designers or users opting for automated information removal based on contextual conditions to protect the privacy and/or security of the users or others. Alternatively, *uncensored capture* value refers to raw cue capturing without pre-selection of conditions related to privacy and/or security. An example of censored capturing is the automatic deactivation of lifelogging cameras near bank ATMs or the upon-demand irreversible blurring of faces in lifelogs. In an uncensored capturing context, the near-continuous cue collection would continue.

2. Trigger This refers to the users' triggering actions to activate the system's cue capturing. *Implicit capture* value is the automatic capturing of cues without explicit triggers from the user. An example is the footage of a surveillance camera or the recording of walking stops by a smart watch. Alternatively, *explicit capture* value refers to collecting cues only on-demand. An example would be capturing a photo from the mobile camera or signing-in to a system to log working hours.

3. Continuity This refers to the granularity of the captured cues. *Selective capture* value refers to recording cues based on predefined contextual conditions such as physical states like high heart rates or environmental conditions such as light. *Continuous capture* value refers to holistic capture of the cues to the maximum frequency allowed by the hardware. A variant would be *near-continuous capture* referring to temporally-scheduled recordings of a particular cue type where the interval is relatively short. An example scenario is if we set up a thermal camera in a school entrance to identify pupils with a fever to support the medical staff in following-up with them later. Selective capturing is capturing photos only of pupils with body temperature higher than 37 $^{\circ}C$ or capturing photos only when there is a person in front of the camera. Continuous capturing is recording a video stream of the room. Near-continuous capturing is the automatic recording of a picture every one minute.

4. Perspective This refers to the captured cues' physical and semantic viewpoints as they can represent the user's perspective or the bystander's perspective on the memory. The *first-person capture* value refers to capturing cues from the personal perspective of the user. The *third-person or the environmental capture* value refers to capturing the cues from the perspective of others which could but does not necessarily include the user's actions. An example is near-continuous recording through a chest mounted lifelogging camera that captures what is in front of the wearer. The photos show the actions of the people surrounding the wearer but the wearer is not in the field of view unless there is a mirror. Thus, it is tricky to conclusively remember the clothes or the actions of the wearer at a particular moment compared to the others showing in the pictures. On the other hand, mounting the camera in the room (the environment) would provide a third-person perspective, i.e. including the user, which possibly provides a better view on the group interactions. Similarly, capturing what a person says through speech recording (first-person) might vary from recording what the others hear (third-person) in crowded contexts like parties.

5. Proxy Technology captures memory cues rather than the actual memory. This parameter refers to the symbolism and abstraction of the captured cues.The *Direct proxy* value refers to recording cues of the intended memory itself. However, the *indirect proxy* value refers to recording generic cues that reminds the user of the intended memory. An example scenario is capturing a reminder of a person's ecstatic reaction to a surprise birthday gift. Direct proxy cues are clear to review even if a person was not part of the memory. However, indirect proxies require contextual prior knowledge of the memory. One could take a third-person video of the moment which would act as a direct proxy cue in the future. Another alternative is capturing an indirect proxy that is a picture of the birthday cake, which would still remind the person in the future of their reaction to the gift because it was a salient event. Another example is monitoring how an experienced researcher writes a paper through capturing a video of the full process (direct proxy) vs. capturing a screenshot every thirty minutes of their laptop (indirect proxy) screen which might also be showing other activities such as social media browsing. However, the cues would probably be understandable to the researcher as they know their context.

3.2.3 Storage Layer

In this section, we discuss the parameters for designing systems to store memory cues. We present the definition of ten parameters, list possible options for each parameter, and provide an example use case for them.

6. Abstraction This refers to the ratio of the stored data compared to the captured data. *Full storage* value refers to storing the full dataset captured. *Summarized storage* value refers to storing only a subset of it. An example is handling the storage of the captured data by a near-continuous clip-on camera taking a photo every thirty seconds. One could either keep the full dataset resulting in approximately 2880 photos per day or keep only the photos without any blurring and with good light conditions. This dimension is critical for space-consuming formats like videos. For example, one month of uncompressed personal photos from a 5 Megapixel camera logging for 9 hours every 30 seconds requires approximately 24 gigabytes of storage.

7. Format preservation This refers to the consistency in the media storage format and/or captured data itself compared to the capturing format. *Same format* value refers to maintaining the capturing format. For example, a system that captures and saves photos as .png files. Alternatively, one could use another format that allows for going back to the original capturing format through post-processing, i.e. the *different but reversible format* value. An example is storing one thousand photos as a single video or saving an audio speech file as text and using a text-to-speech application to present it later. Lastly, one could use another format that does not allow for going back to the capturing format, i.e. the *different but irreversible format* value. An example is mapping heart rate data to the sound track speed without storing the speed factor mapping. Format changing is used to save storage space and for privacy and/or security reasons. An example for changing the data without the media format is blurring a person's face in a photo then deleting the original photo.

8. Security This refers to how the data is being secured in the storage location. We focus on two design aspects: the *encryption* and the *sign-in*. The *encryption* aspect refers to whether the data is stored in the original format (decrypted) or transformed to a reversible unrecognizable format for privacy and/or security reasons (encrypted). With the current laws about data protection, there are clear implications and guidelines for designers and

researchers to always store the data encrypted even on local devices such as their personal laptops. However, this adds to the overhead while analyzing and utilizing the data. For example, one week of lifelog photos taken every 30 seconds takes approximately 15 minutes to encrypt on a core i5 laptop, and 30 minutes to decrypt it using a local hash key. The second aspect, *sign-in*, refers to the user authentication the system requires to allow data access and interaction from the user. An example is asking for a password to decrypt the stored cues.

9. Deletion governance This refers to the scope of data deletion. One option is the *delete-for-me* value, which hides the content from the user while preserving it for others. Another is the *delete-for-others* value, which hides the content from others but keeps it for the user. The last option is the *delete-for-all* value which entirely removes the trace of the content. For example, consider the deletion of messages in a group chat. A user can choose to hide some messages from their phone (delete-for-me) vs. delete the content for everyone in the group chat (delete-for-all). Similarly, a person can untag themselves from a photo on social media (a proxy to delete-for-me) vs. changing the privacy of the photo to be private, revoking the access of others (delete-for-others), or completely removing the picture from the platform (delete-for-all).

10. Personal authorization This refers to whether others are allowed to store and/or download content including the user, or not. We focus on two design aspects: *authorizing storage*, and *authorizing download*. Designers should decide about the autonomy level provided for the users to allow or ban the storage of any content including them and the download of such content. For example, social media platforms like Facebook and Instagram now provide on-demand protection mechanisms banning the download of profile pictures or taking screenshots from the profile. One could also imagine with the prevalence of automated tagging on social media platforms that bystanders in a photo are informed and asked for consent before the upload of the photo.

11. Access rights This refers to who has access to the stored cues. The *Personal access rights* value refers to private storage of the cues accessible by one entity. The entity could either be the user or the system administrator. The *Shared access rights* value refers to sharing the cues with a specific set of people or publicly. An example scenario is storing birthday party photos in a private Google photos folder (personal access rights) vs. sharing the

album with friends who attended the party or publishing them on your personal web page (shared access rights).

12. Location This refers to the location and accessibility of the data repository. The *Local storage* value refers to data storage on personal devices only such as laptops or mobiles. The *Cloud storage* value refers to uploading the data to external servers such as university repositories or Dropbox. An example of local storage is storing the gallery photos on the mobile only vs. allowing automatic synchronization on a cloud service like Google photos.

13. Backup This refers to the underlying mechanisms for copying the data to store it in another location. The *Manual backup* value refers to the user explicitly triggering and/or performing the copying process. Then *Automatic backup* value refers to the system implicitly triggering and performing the copying process. For example, a user copying the photos in their mobile gallery to their Google drive is considered manual backup. Similarly, a user clicking the (backup now) button to trigger automated upload of photos in the gallery is still considered manual backup. However, the mobile automatically backing up the photos every midnight is automatic backup.

14. Syncing This refers to the case where the final storage destination is different than the capturing device due to limited in-house space. For example, clip-on cameras and fitness trackers have limited space and require regular synchronization and deletion of data, unlike laptops. We focus on two design aspects: *destination* and *frequency*. The *Destination* aspect refers to the final location of the data storage. The *Frequency* aspect refers to to the backup type and interval between consequent backups. For example, the narrative clip camera requires syncing approximately every two days and a local syncing session to the laptop takes around fifteen minutes.

15. Inheritance This refers to the ownership of the stored data in case of emergencies where the user is incapable of taking decisions or deceased. For example, a user can give access to all your digital accounts and name a predecessor that gets legal access to all the content after the user's death or in case of emergencies. There is growing body of literature and commercial services investigating this topic. However, it does not fit within the scope of this thesis.

3.2.4 Presentation Layer

In this section, we discuss the parameters for designing systems to show memory cues. We define eleven parameters, list possible options for each parameter, and provide an example use case for them. The parameters serve three functions: selection, formatting, and consumption of memory cues.

- The *Formatting* category groups three parameters tackling how the memory cues are presented to the user. The parameters are: *16. format preservation*, *20. materiality*, and *21. persistence*.
- The *Selection* category groups three parameters tackling how the displayed cues are chosen. The parameters are *17. abstraction*, *18. scope*, and *19. curation*.
- The *Consumption* category groups five parameters tackling how the user interacts with the displayed cues. The parameters are *22. system trigger*, *23. access rights*, *24. required attention*, *25. integration*, and *26. density*

16. Format preservation This refers to the consistency in the media presentation format and/or stored data compared to the storage format. The *Same format* value refers to maintaining the data storage format. For example, playing the voice recording of a sentimental message from a loved one. The *Different but reversible format* value refers to displaying a different format compared to the stored one. However, it shows the content of the original format. For example, showing the content of the the voice recording as text. The *Different but irreversible format* value refers to displaying a different format from the stored one. However, the new format conceals the content from the original format; for example, showing only excitement metrics generated from the pitch analysis of the voice recording without displaying the actual content of the voice note.

17. Abstraction This refers to the optimization of the presentation method and the number of presented cues to optimize the interaction technique. The *Full cues* value refers to displaying the collected cues without changes. The *Summarized cues* value refers to grouping the cues together or reducing them using predefined semantics to minimize the cognitive load of processing them. For example, we can display a collection of 2000 photos of lifelogs in a gallery view (i.e. full cues) or group them into relevant events and display only one photo per event for an overview (i.e. summarized cues).

18. Scope This refers to the post-processing of several memory cues to create holistic findings about the user's behaviour. The *Original cues* value refers to displaying the raw captured memory cues. The *Meta cues* value refers to identifying and displaying meta findings about the memory. For example, one could display a graph of heart rate measurements during a day next to twenty photos taken in the same day (i.e., original cues) or use the heart rate data as a background proxy for excitement and display only the photos size-coded by excitement, where larger photos represent moments of excitement (i.e. meta cues).

19. Curation This refers to the election process of a subset of the captured cues to be presented to the user. The *Manual selection* value refers to the user explicitly selecting the memory cues they would like to include. The *Heuristic selection* value refers to automatically selecting content based on predefined contextual conditions in the system such as displaying content from the same geographical location or high quality photos that have no blurring or dark spots. The *Random selection* value refers to the automatic selection of the cues by the system without predefined conditions. Those strategies are not mutually exclusive and are often combined by system designers. For example, there are social media applications reviewing posts from previous years that happened the same day the user is checking the application. They use heuristic selection that is the temporal resemblance with the day then random selection to choose the final post. An example of manual selection is the user choosing the photos for an electronic frame in the living area.

20. Materiality This refers to the medium for presenting the memory cues. The *Physical presentation* value refers to collecting physical mementos or manipulating physical objects to display a memory. An example is changing the color of an ambient light in a smart home to reflect the heart rate changes of the inhabitants. The *Digital presentation* value refers to memory cues being displayed only within another electronic medium. It covers a wide spectrum such as social media content, mobile activities and logging, and work digital tools. The *Mixed presentation* value is a trade-off between physical and digital presentations where digital memory cues are presented on or experienced through real world objects. An example is taking a virtual tour through a recently visited route.

21. Persistence This refers to the ability of the user to record the displayed memory cues to review on-demand later. The *Permanent presentation* value refers to cue presentations available for reuse and review on-demand.

An example is the collage photos automatically created by Google Photos from similar photos in the same location. The *Transient presentation* value refers to temporary ephemeral presentations of memory cues that cannot be recorded. An example is displaying a photo taken at a specific geographical location whenever all persons in the photo are in the same place without allowing the download of the photo.

22. System trigger This refers to the user's role in prompting the system to show a memory cue. The *Passive system* value refers to systems requiring users to explicitly request a memory cue. The *Active system* value refers to systems automatically showing memory cues without the user's intervention. For example, Google photos is a passive system when the user searches for a specific photo and is a proactive system when it automatically sends notifications about automatically curated photos from past years on the same day.

23. Access rights This refers to the bystanders' predefined allowed actions to *consume* and *interact* with the displayed memory cues. The *Consumption* design aspect refers to the bystanders' rights to passively view the memory cues with the user. Bystanders in this section refer to other individuals that are not the owners of the captured memory cue. The *Interaction* design aspect refers to who can actively comment, add or manipulate the memory cue besides the user. There are three governance levels for consumption and interaction: *personal* where only the user controls the content, *semi-public* where a specific set of people are involved like friends and *public* where content is available for masses. Consumption highly depends on the display location. For example, the user's photos in a Maldives trip could be consumed personally when viewed alone on the mobile, semi-publicly when the photos are shown to the roommates on the e-frame in the shared apartment and publicly when the user uploads the photos to their personal website. Similarly, users and system designers can decide on the interaction level. For example, the user can give viewing rights only to the website photos or allow comments to increase the bystanders' interaction.

24. Required attention This refers to the focality of the displayed memory cues. The *Active cues* value refers to the user focusing primarily on the memory cues. The *Ambient cues* value refers to the system displaying the memory cues being in the background and unobtrusive to the user's current activities. For example, an electronic frame placed in a living room and automatically showing photos will usually be in the background (i.e. ambient cues).

However, if the user faces it to watch the latest photos from their trip, the system would be showing active cues.

25. Integration This refers to the connection of the displayed memory cues to other viewing experiences. The *Standalone cues* value refers to presenting the memory cues alone as the sole focus of the system. The *Embedded cues* value refers to including the memory cues as a part of other experiences such as watching TV or doing sports. An example of standalone cues is a e-photo frame showing photos from the latest Christmas trip. An example of embedded cues is displaying a television overlay showing the user how excited they were when they watched the Christmas episode from "Friends" last year while re-watching it this year.

26. Density This refers to the number of times the system repeats a particular memory cue, the duration for presenting the cue and the number of selected cues in a single session to impact the memory. For example, Li et al. [158] showed that the optimal number of photos for video summaries of daily lifelogging photos is 40 photos displayed for three seconds each.

3.3 Media Selection

Memory cues are captured, stored and presented through media. Media in this context refers to the data format selected to represent a cue. Examples of media include but are not limited to photos, text representations, biological signals and music. In Section 3.3.1, we present criteria for evaluating media types to select an appropriate one for representing a memory cue to serve the memory alteration scenario. In Section 3.3.2, We will use these criteria for evaluating the media types we used in our research projects.

3.3.1 Selection Criteria

In this section, we present design criteria to evaluate the suitability of a medium in a memory alteration scenario. We group the criteria by the framework layers they target. Criteria 1 and 2 (*device accessibility and device portability*) target constraints related to the capture layer. Criterion 3 (*storage consumption*) targets storage layer constraints. Criteria 4 to 7 (*informational density, objective fidelity, reproducability, and consumption speed*) tackle presentation layer constraints. Finally, criterion 8 targets user expectations.

1. **Device accessibility** This refers to the niche prevalence of the devices and technologies used to capture the cue in the required medium. For example, mobile phones are highly accessible to laymen.

2. **Device portability** This refers to the mobility of the capturing device supporting the medium type with the user. Higher portability corresponds to higher freedom of movement with the device. For example, mobile phones are highly portable while environmental surveillance cameras are not.

3. **Storage consumption** This refers to the storage space needed to save the cues in the selected medium. The medium feasibility should be evaluated also with respect to the capturing continuity. Higher consumption corresponds to faster depletion of storage units. For example, photos are preferable to videos on mobile phones for continuous capturing from a space-preserving perspective.

4. **Informational density** This refers to the number of basic and conceptual cues found in a medium. Higher density corresponds to a higher number and/or quality of cues in the captured or presented memory cue. Basic cues are like colors and shapes. Conceptual cues are like faces and landmarks. For example, clear photos of an event have higher density than text descriptions of participants.

5. **Objective fidelity** This refers to the degree of resemblance between the captured content and the real event. Higher fidelity corresponds to higher mimicking of the real event. For example, a photo is more objective than a text description of a birthday cake.

6. **Reproducibility** This refers to the simplicity of digitally replaying the stored cues. Higher reproducibility corresponds to higher simplicity in reusing the cues. For example, flavors are complicated to regenerate through virtual devices.

7. **Consumption speed** This refers to the simplicity of browsing and understanding large datasets of memory cues using the selecting medium. Higher consumption speed corresponds to the fast simple knowledge impartion using the selected medium. For example, browsing 100 photos in the gallery to search for a particular photo is faster than reading textual descriptions of the photos.

8. **Social acceptability** This refers to the general consensus of the users about privacy and security risks associated with the selected medium. Higher acceptability corresponds to less user apprehension about the technology.

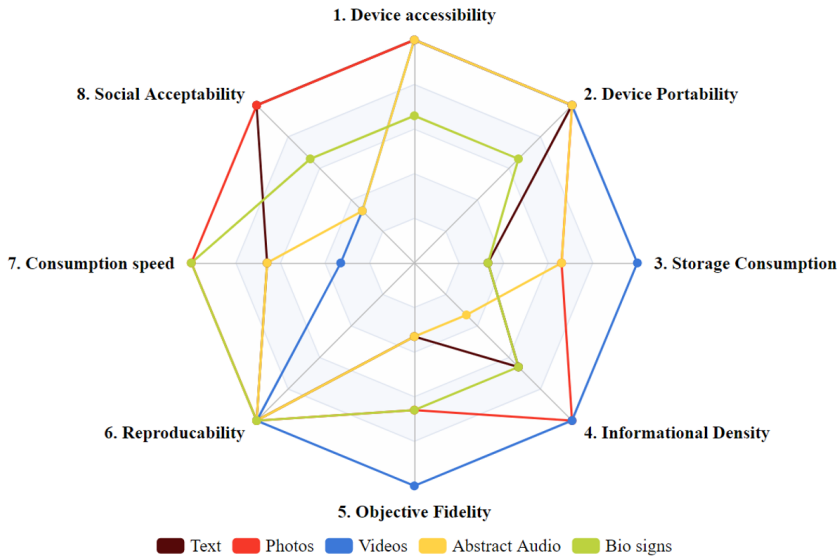

Figure 3.4: Summary of the parameters for selecting media used in our projects. We represent each criterion through three levels: low (inner edge of the spider figure), medium, and high (outer edge of the spider figure). The connotation of the higher value is contextual and is discussed in Section 3.3.1

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For example, capturing videos is more controversial than capturing photos as they have a higher likelihood of capturing sensitive information.

3.3.2 Media Types in Research Projects

In this section, we cover five common media cues as an example of how to apply the proposed parameters in Figure 3.4 to evaluate a media type. These are: text, photos, videos, audio, and biological signals. Combining the media results in multimodal representations of memories. We reflect below on the usability of each medium using the aforementioned criteria described in Section 3.3.1.

Text In this context, we are referring to text created by the user to preserve a memory such as diaries and social media posts. It is limited in its informational density to the quality of the user's description. It has a limited

objective fidelity as it focuses on capturing the user's subjective opinion about the memory rather than mimicking reality. Devices producing text are highly accessible and portable, such as mobile phones, laptops, or pen and paper. It is the most efficient medium in the list from a storage perspective. However, it requires the user's active engagement to create the content compared to photos and videos for example, as those can be automatically captured. The content is easily reproducible and fast to consume in smaller datasets like social media posts. However, it is time-consuming with larger datasets. An example is that it takes longer to review one-paragraph-per-day diary entries written through a year compared to watching one photo per day. It is also highly socially acceptable as it provides a personal account of the events that could be refuted by others in case of conflicts over sensitive situations.

Photos Photos in the modern world are used for capturing rich in-situ memory cues. Currently, they are among the most commonly used cues whether through explicitly-captured photos via mobile phones or through implicitly-captured ones through lifelogging cameras. This can be attributed to the high accessibility and portability of the capture devices. The format is popular because it offers a good trade-off between high informational density and incompleteness, enabling reasonable doubt when it comes to sensitive content, unlike videos. They also provide an objective capture of the events though possibly distorted by environmental conditions like shooting angles and light. Moreover, they are easy to capture and edit through abundant niche ubiquitous technologies with high social acceptability. Additionally, they are more space-efficient for storage compared to videos, and they are easy to reproduce. They are also quickly consumed by users even in larger datasets as social media normalizes the browsing of tens (or even hundreds) of photos per day.

Videos These are the holistic sister of photos. Their informational density is superior due to continuity of capture and inclusion of other cues like audio. Similar to photos, there is an abundance of stationary and mobile capturing devices and it is simple to use them. However, their storage consumption is the highest in this list.Thus, they are less convenient for longer mobile capturing periods. They provide a high degree of objective fidelity; however, their social acceptability is low for personal near-continuous capture in (semi-)public spaces because they pose a violation to the bystanders' privacy and do not provide room for interpretation of the user's actions in embarrassing / sensitive situations. However, shorter versions (seconds to a couple of minutes long) like vines are popular on social media. Browsing

larger datasets is time-consuming without appropriate speed-reviewing methods as it requires the same time spent in the original event. However, they are easily reproducible.

Abstract audio We differentiate here between speech and abstract audios like music. In our projects, we only used abstract audios. Thus, we report about it in Figure 3.4. However, we report here on speech as well for the sake of completeness in contrasting and highlighting the properties. Speech provides medium informational density as the intonation and the speed could cue emotional memories besides the spoken content. On the other hand, the informational density of abstract audios is highly dependent on the audio's nature and association to the user. Speech has a high objective fidelity if captured within the live event. Narrations about events though have low objective fidelity similar to text as they focus on the subjective view of the narrator. Abstract generic audios have a low objective fidelity. However, in-situ generic recordings can have a medium objective fidelity in case of salient events. For example, consider a recording that has the sound of an exploding balloon in a birthday. It mimics this particular event objectively. Devices recording audio are highly accessible and portable, making it a storage-efficient format whereby the captured content is easily reproducible. The consumption speed is situational. For example, a 30-second voice note is faster to consume than eight long chat texts. However, a lecture slide deck could be faster to browse than a one-hour audio recording of the explanation. Audio is generally socially unacceptable when it involves live recordings of private interactions with other bystanders, similar to videos.

Biological signs This refers to biometrics such as heart rate, brain waves, steps count and weight. The raw captured content has low informational density. Combining cues into higher abstract versions could be informative in the (presentation) layer of the systems. They have high objective fidelity as they capture the person's state as is in a situation. Capturing devices like smart watches, fitness trackers and mobile phones are accessible and portable. However, high-quality capturing devices such as EEG caps and chest straps have low accessibility and portability. They are space-efficient and easily reproducible. The cues are easy to understand and fast to consume with the right presentation techniques. Their social acceptability is situational and culture-based, and users can be apprehensive about the public data sharing.

3.4 Summary

In this chapter, we introduced a framework for designing ubiquitous memory interventions. We reflected on common goals for memory alterations, namely memory augmentation, memory attenuation and memory implantation. Afterwards, we introduced the technical pipeline named *"MemAlt"* for implementing such systems. It is composed of four layers: infrastructure, capture, storage and presentation layer. We focus for the remainder of this manuscript on the capture, storage and presentation layers in designing our research projects. Figure 3.3 summarizes the framework parameters. Lastly, we introduced criteria for selecting appropriate media types to represent memory cues in ubiquitous memory interventions. We used the criteria to reflect on the media types we used within this manuscript (text, photos, videos, abstract audios, and EEG data). We use the foundation built here in the upcoming part to design and evaluate our projects.

III

Methodology

Chapter 4

Research Projects Map

In this chapter, we introduce an overview of the eight research projects covered in this thesis. First, we present the reader the rationale behind selecting those projects and the limitations of our selection criteria. Afterwards, we provide a short summary for each project. The contribution of this manuscript's author in each project is also summarized.

4.1 Projects' Selection Criteria

We wanted to design projects covering the spectrum of memory alteration strategies: augmentation, attenuation, and implantation within *healthy adults* (see Section 3.1). The objective of the designed projects was not demonstrating the changes in memory. Memory changes in realistic setups are challenging to pinpoint and generalize without larger samples beyond the scope of this thesis. Additionally, there is rich Psychology literature achieving this goal. Our goal and contribution is facilitating the design of ubiquitous-computing systems for memory alterations. Thus, the main objective of the projects is experimenting with the design process of the systems to distill the MemAlt parameters discussed previously in Section 3.2.

To diversify our use cases, we created a design space for the systems altering memories composed of two parameters: system strategy and memory strategy.

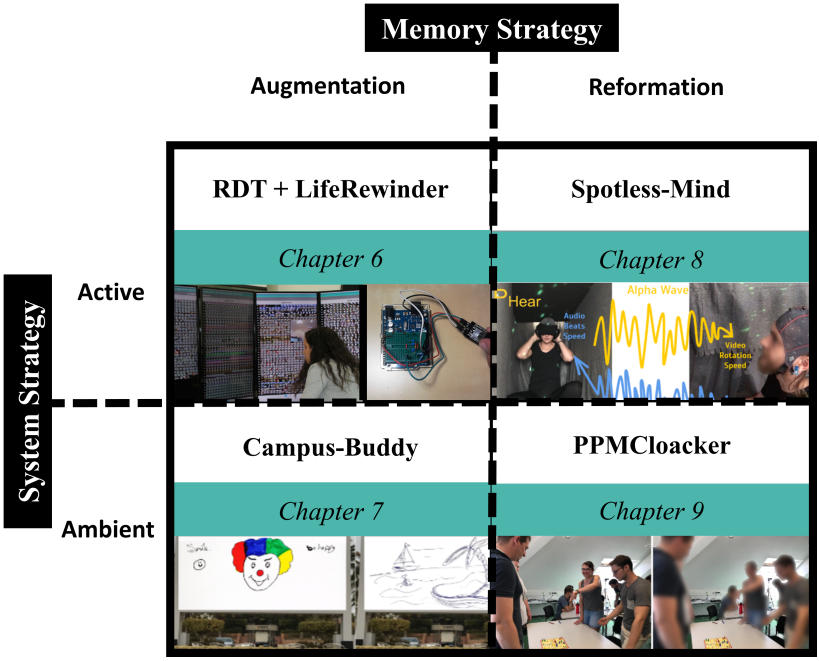

Figure 4.1: Overview on the projects used to explore the memory strategies. RDT, LifeRewinder, and PPMCloak are lifelogging projects. The objective of the first two is creating an external memory augmentation prosthetic. Complementarily, the last explores memory attenuation and implantation as a side effect to protecting the users' privacy by blurring and deleting lifelogs. SpotlessMind is a Brain-Computer Interface for artistically sharing abstract memories between two people while bystanders watch. CampusBuddy is a study for optimizing content on a public display for the students to create an ambient sense of familiarity.

System Strategy This refers to the deliberation of the system designer to induce a memory alteration. *Active strategy* refers to systems primarily designed to cause memory alterations. Users explicitly consent and understand that such systems are memory prostheses. An example is visual systems augmenting the memory of dementia patients. *Ambient strategy* refers to background memory alterations resulting from using systems. Users are unaware of the potential changes happening to their memory through regular usage of the systems. The memory alteration in this case is either an accidental side effect or a hidden target by system designers. An example of hidden target systems are algorithms optimizing the repetition

Table 4.1: Overview on the contribution of the this manuscript's author in each research project. Green cells indicate the author contributed significantly in the project role. Dotted cells indicate that the project did not require this project role. White cells indicate that the role was primarily lead by the collaborators.

Project Role	Prisoner OfWords	RDT	Life Rewinder	PPM Cloaker	Campus Buddy	Spotless Mind	E-Ally	Pandora Box
Project idea								
Prototype requirements								
Prototype implementation								
Study design								
Study material								
Running study								
Data analysis & documentation								
Paper writing								

of advertisements online to increase their memorability. An example of an accidental side effect scenario is mobile users being more forgetful of phone numbers they once memorized and relying on their devices instead for recalling them, which is a classic case of memory attenuation.

Memory Strategy We discussed the three memory alteration strategies: augmentation, attenuation, and implantation in detail in Section 3.1. We grouped memory attenuation and implantation into one category named *memory reformation*. The reason is they usually coexist as a side effect to each other and require larger sample sizes to clearly separate them.

Figure 4.1 gives an overview of the design space and the corresponding five projects to explore it. The five projects are example use-cases of using MemAlt as a tool for (1) designing technological interventions and (2) evaluating them. We also designed another two projects to further understand users' expectations of other people and systems utilizing their shared memories on social media as an example for a memory prosthetic (**PandoraBox** and **E-Ally**). Additionally, we designed a project to develop tools for memory examination in the wild (**PrisonerOfWords**). In the next section, we discuss each project in detail. Figure 4.1 summarizes the contribution of this manuscript's author in each of the research projects.

All projects targeted retrospective memory failures as these are more common and more likely to be addressed by passive systems [46], except for **CampusBuddy** that included both retrospective and prospective memory failures as it included reminders about future events. **RDT**, **LifeRewinder**, and **PPMCloak** targeted

episodic memories, while **SpotlessMind** and **CampusBuddy** targeted semantic memories as we did not control what the participants thought of in **SpotlessMind**, and some of the information requested in **CampusBuddy** was factual and did not directly relate to the experiences of the participant. **PrisonerOfWords** focused on short-term memory recall while the rest targeted long-term recall.

4.2 Projects' Overview

In this section, we introduce our eight research projects presented in this thesis. We present an abstract of the project's idea, a name for the project that is used throughout this manuscript, an overview of the research methodology and the resulting publications.

4.2.1 Inspecting Memories via Mobile Games

Project Type: Deployed prototype and in-the-wild experiment
Research Type: Experimental research - Descriptive research - Replication research
Research Methods: Within-subject mobile experiment - Gamification - Descriptive statistics
Discussed in: Chapter 5

We denote this project as **PrisonerOfWords**. We explore the collection of textual memory cues by taking controlled Psychology experiments into the wild via a mobile game. We extend here the gamification research method by offering a design process for gamifying memory experiments. We specifically target memory experiments as they differ from and sometimes contradict design constraints of other gamified mobile experiments. We achieve this goal via prototyping and deploying a mobile Game called "Prisoner of Words". In this game, we replicate an existing Psychology lab experiment. We show that our results from a two-week deployment conform with the longer lab experiment.

This project is based on the following publication(s):

P. ElAgroudy, P. Khoshdani, T. Dingler, G. Ward, P. W. Woźniak, and A. Schmidt. Prisoner of words: Lessons learnt from mobile gamification of lab memory experiments. In *Extended Abstracts of the 2021 Annual Symposium on Computer-Human Interaction in Play (CHI Play)*, pages 256–261, 2021

4.2.2 In-Situ Longitudinal Lifelogging Case Study

Project Type: Deployed prototype and lab experiment
Research Type: Experimental research - Quantitative research - Qualitative research - Observational research - Case study
Research Methods: Within-subject lab Experiment - Semi-structured Interviews - Recall/recognition questionnaire - Concealed Memory Collection (CMC) - Statistical analysis - Automated Memory Validation (AMV) - Inductive coding - In-Vivo Coding - Values coding - Narrative ethnography
Discussed in: Chapter 6

We denote this project as **RDT**. We designed a full-stack deployment and utilized it for a longitudinal lifelogging field study. Our prototype is an example of an active memory augmentation prosthetic. The experiment lasted for thirty days where participants recorded their lives through automatic photos taken every thirty seconds from a chest-mounted camera. We also showed participants automatically curated slideshows summarizing their days and had an initial exploration of the impact of such summaries on their memories. Through this project, we were also able to explore how to visualize large datasets of lifelogs.

This project is based on the following publication(s):

P. Elagroudy, T. Machulla, R. Rzayev, T. Dingler, M. Funk, A. Schmidt, G. Ward, and S. Clinch. Impact of reviewing lifelogging photos on recalling episodic memories. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing, UbiComp Adjunct 2016, Heidelberg, Germany, September 12-16, 2016*, pages 1014–1019. ACM, 2016

4.2.3 Speed Reviewing of Lifelogs Using Tangibles

Project Type: Prototype and lab experiment
Research Type: Exploratory research
Research Methods: Within-subject lab Experiment - Focus group - 365 Brain writing method - Inductive coding - Process coding
Discussed in: Chapter 6

We denote this project as **LifeRewinder**. This project is about optimizing browsing and interaction with large datasets of pictorial lifelogs within a memory prosthetic. Our target is to enable users to get a quick overview of their daily activities documented through 2000 photos per day on average. As a side goal, we want to also minimize the search time for photos representing particular events in the day. Thus, we explore the optimization of sequential reviewing, that is reviewing a single photo at a time. We use varying speed as a design element to optimize the browsing process. To this end, we explore the usage of a tangible knob to interact and review the daily photos in a video-like stream format with varying speed. We build the prototype of the knob and evaluate its usability and use cases.

This project is based on the following publication(s):

P. Elagroudy, C. Soliman, S. Abdennadher, and A. Schmidt. Liferewinder: speed reviewing of lifelogs using tangibles. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays, PerDis 2019, Palermo, Italy, June 12-14, 2019*, pages 30:1–30:2. ACM, 2019

4.2.4 Memory Reformation via Symbiotic Sharing

Project Type: Proof of concept prototype and user study
Research Type: Descriptive research - Qualitative research - Exploratory research - Ethnography
Research Methods: Speculative design methods - Online Survey - Descriptive statistics - Priori coding - In vivo coding - Values coding
Discussed in: Chapter 7

We denote this project as **SpotlessMind**. We investigate how people want to share and present internal mind states with others via implicit biological sensing. As an example, we focus on a pseudo-state called *brain occupancy*, referring to the person being mentally busy thinking about something such as a memory. We consider this project a form of sharing an abstract memory with others. This project is formed of speculative design study and a proof-of-concept prototype to test the feasibility of the design idea. In the project, we artistically express the occupancy of two people to one another through abstract curated video and audio while considering the bystanders' experience. We envision using this work to actively alter the current recalled memories as one sharer tries to synchronize their mental state with the other.

This project is based on the following publication(s):

P. Elagroudy, X. Wang, E. Stemasov, T. Hirzle, S. Shishkovets, S. Mehrotra, and A. Schmidt. Spotlessmind: A design probe for eliciting attitudes towards sharing neurofeedback. In *Proceedings of the Augmented Humans International Conference, AH 2020, Kaiserslautern, Germany, 16-17 March, 2020*, pages 24:1–24:8. ACM, 2020

4.2.5 Ambient Familiarity via Public Displays

Project Type: User study
Research Type: Qualitative research - Exploratory research - Ethnography
Research Methods: Focus group - Brainstorming - Inductive coding - Values coding - Versus coding - Affinity analysis
Discussed in: Chapter 8

We denote this project as **CampusBuddy**. This project is a design workshop for public display content that fosters a sense of familiarity, control and mental wellbeing. We develop our work in a university context with students. We envision using memorable content types to ambiently augment the students' memory to enhance their knowledge of their surroundings. We focused on three stakeholders: junior students, senior students and academics. We conducted several design and brainstorming activities to elicit the user needs then categorized and analyzed them to generate use cases for the content and design guidelines.

This project is based on the following publication(s):

S. A. Safwat, E. Osama, P. Elagroudy, and S. Abdennadher. Campusbuddy: how can campus public displays help students feel at home? In *Proceedings of the 8th ACM International Symposium on Pervasive Displays, PerDis 2019, Palermo, Italy, June 12-14, 2019*, pages 27:1–27:2. ACM, 2019

4.2.6 Privacy-Aware Lifelogs Reforming Memories

Project Type: Experiment
Research Type: Experimental research - Descriptive research
Research Methods: Between-subject lab experiment - Focus group - Custom recall and recognition questionnaires - Descriptive statistics - Recall Correctness Score (RCS)
Discussed in: Chapter 9

We denote this project as **PPMCloak**. We compare storage and presentation methods of lifelogs to protect the privacy of bystanders who do not wish to appear in photos. We achieve this by comparing deletion of content (manipulating stored cues) vs. altering the captured photos through blurring (manipulating presented cues). Through this controlled lab study, we explore the use case of environmental lifelogging and collective memories of groups, where cameras record group sessions for activities and the photos are used as later memory aids for participants. We show in this project the potential of using altered lifelogs for ambient memory alterations such as memory attenuation and implantation.

This project is based on the following publication(s):

P. Elagroudy, M. Khamis, F. Mathis, D. Irmscher, A. Bulling, and A. Schmidt. Can privacy-aware lifelogs alter our memories? In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems, CHI 2019, Glasgow, Scotland, UK, May 04-09, 2019*. ACM, 2019

4.2.7 Memory Sharing Conflicts in Women E-Groups

Project Type: Research Agenda
Research Type: Observational research - Autoethnography
Research Methods: Journaling - Reflective writing - Narrative ethnography - Archival records backtracking
Discussed in: Section 10.1

We denote this project as **E-Ally**. In this account, we highlight the privacy challenges and the social repercussions of sharing personal memory narratives on social media. We focus on the rich design opportunities for a marginalized user group, that is the women in the MENA (Middle East and North Africa) region. We dissect the phenomenon of sharing memories, problems and asking for advice on Women-Only Facebook groups. Through this narrative, we highlight how social and cultural norms are translated into the usage patterns, missing user needs in the current platforms, new social problems arising from these interactions and how endangering they are for the users. The researchers in this project are also members of the groups and this project is an autoethonographical work of their observations and interactions with the members.

This project is based on the following publication(s):

P. Elagroudy and M. Saleh. We have each others' backs: A study on women only facebook groups. In *Adjunct Proc. CHI Workshop on Sensitive Research, Practice and Design in HCI*, 2019

4.2.8 Surprises from Smart Social Media Interactions

Project Type: User study
Research Type: Descriptive research - Qualitative research - Exploratory research
Research Methods: Survey - Critical incident recall - Self Assessment Manikin (SAM) - In vivo coding - Values coding - Versus coding
Discussed in: Section 10.2

We denote this project as **PandoraBox**. This project is a case study investigating what people remember about "intelligent platform interactions" over social media. Intelligent interactions refer to platform responses that are unpredictable to the user and might be derived from analyzing the user's behavior on the user's behavior history on/ off the platform. We use Facebook as an example of social media platforms because it is widely used by our sample group from non-expert non-WEIRD (Western Educated Industrialized Rich Democratic) communities. Our exploration highlights incidents recalled by the participants, their emotional impact on the participants and their impact on the user's perception of the platform. The objective is to unravel the users' perception of the impact of sharing memories and data with intelligent systems.

This project is based on the following publication(s):

P. Elagroudy, M. Saleh, C. Sturm, and A. Schmidt. How do users expect their smart memory vaults to utilize their shared memories? In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA, 29 April 2022 - 5 May 2022*, pages 448:1–448:6. ACM, 2022

Chapter 5

Research Methods

In this chapter, we summarize the research methods we used within all projects to collect and analyze the data (see Figure 5.1). The figure has three parts: (1) *project type* highlighting the project outcome, (2) *research type* categorizing our approach, and (3) *research method* summarizing the tools to reach our goal. We used a mix of standard methods and extended existing methods to achieve specific research goals. Section 5.1 describes a subset of the standard methods. Section 5.2 presents the extended methods and reflects on their use cases.

Parts of this chapter are based on the following publication(s):

P. ElAgroudy, P. Khoshdani, T. Dingler, G. Ward, P. W. Woźniak, and A. Schmidt. Prisoner of words: Lessons learnt from mobile gamification of lab memory experiments. In *Extended Abstracts of the 2021 Annual Symposium on Computer-Human Interaction in Play (CHI Play)*, pages 256–261, 2021

5.1 Standard Methods

We consider most of the methods used as domain standards. Thus, we shortly review key points about them to facilitate following up on the methodology

Table 5.1: Overview on the methods used in all our research projects. Green cells mark the used methods. The red asterisk (*) marks methods we extended from prior work to fit the constraints of our research.

		Prisoner OfWords	RDT	Life Rewinder	Spotless Mind	Campus Buddy	PPM Cloak	E-Ally	Pandora Box
RESEARCH TYPE									
	1. Experimental research	■	■				■		
	2. Descriptive research	■			■		■		■
	3. Quantitative research		■						
	4. Qualitative research		■		■	■			■
	5. Observational research		■					■	
	6. Exploratory research			■	■	■			■
	7. Case study		■						
	8.Ethnography				■	■			
	9. Auto ethnography							■	
	10. Replication research	■							
RESEARCH METHOD									
Data Collection Method	1. Within-subject experiment	■	■	■					
	2. Between-subject experiment						■		
	3. Mobile games *	■							
	4. Interviews		■						
	5. Focus groups			■		■	■		
	6. Brainstorming					■			
	7. 365 brain writing			■					
	8. Speculative design methods				■				
	9. Survey				■				■
	10. Recall/recognition questionnaire *		■				■		
	11. Critical Incident Recall								■
	12. Concealed Memory Collection (CMC) *		■						
	13. Self Assessment Manikin (SAM)								■
	14. Journaling							■	
	15. Reflective writing							■	
Quantitative Analysis	16. Descriptive statistics	■			■		■		
	17. Statistical analysis		■						
	18. Automated Memory Validation (AMV) *		■						
	19. Recall Correctness Score (RCS) *						■		
Qualitative Analysis	20. Inductive coding		■	■		■			
	21. Deductive (priori) coding				■				
	22. In vivo coding		■		■				■
	23. Values coding		■		■	■			■
	24. Process coding			■					
	25. Versus coding					■			■
	26. Affinity analysis					■			
	27. Narrative ethnography		■					■	
	28. Archival records backtracking							■	

description in the upcoming chapters. We encourage the reader to check [201] for a concise overview of the research types.

Experiments and studies We differentiate between experiments and studies by the presence of hypothesis, and conditions in an experiment when a study only has research questions.

Journaling and reflective writing We differentiate between journaling and reflective writing by the focus of the writing process. Journaling is about documenting incidents using any means such as writing or sketching. However, reflective writing focuses on the argumentation, validity and author's reflection on the writing. For example, journaling a birthday event might focus on describing the cake celebration and the attendees. Reflectively writing about it would focus on how the author felt along with the factual details.

Qualitative coding types Inductive coding starts without prior assumption about the data and distills the codes from the data. However, deductive coding starts with a closed set of codes that could be updated later in the coding process. In vivo coding focuses on giving a voice to the participants. Values coding focuses on attitudes and trends in the data. Process coding focuses on the actions of the participants. Versus coding focuses on the discrepancies in behavior between two or more user groups.

Archival records backtracking and narrative ethnography Archival records backtracking focuses on the research, finding old incident evidence through autoethnography and re-analyzing it. An example would be a researcher using autoethnography and observing behavior in a closed social media group. A year later, they may be writing a paper and remember seeing posts about a particular incident, and backtrack to find them. Narrative ethnography incorporates the researcher's remarks and reflections on the participant's view.

6-3-5 brain writing [213] This is a brainstorming method for collecting as many ideas as possible in a short time without fixating on the initial quality. In this method, the researcher specifies a research question and communicates it with the participants. The method is performed with six participants simultaneously. Each participant has a 6 rows * 3 columns paper grid. In the first round, each participant should write three ideas answering the research question in the first row. A round lasts for five minutes. Afterwards, the researcher asks the participants to pass their paper to the person on their left. In the next round, they should all fill the next row with three ideas either new or inspired by the other ideas written in the paper. The method allows participants to be inspired by other answers without worrying about some participants overshadowing the contribution of the others.

One session typically lasts for 30 minutes. generating 108 ideas. Afterwards, the group is asked to work together to consolidate the ideas into common themes and present them. We use this method in the **LifeRewinder** project.

Critical Incident Report (CIR) [209] This is a method to anonymously collect details about a particular incident. Participants are asked to recall an incident that answers the researcher's question. Afterwards, they should fixate on the incident and answer the rest of the experimental questions about it. This method is mainly used to collect sensitive research data about possibly troubling topics to the participants. We use it in the **PandoraBox** project.

Self Assessment Manikin (SAM) [98] This is a tool to evaluate the affect of participants towards a certain topic using sketched manikins. It focuses on three metrics: pleasure, arousal and dominance. Pleasure describes the valence associated with the reported topic. Arousal describes how interesting the topic was perceived. Dominance describes the prevalence of the reported emotions about the incident. We use it in the **PandoraBox** project.

5.2 Tailored Methods

In this section, we present four methods we extended from prior work to fit the constraints of our experiments, and coined their names (marked with * in Figure 5.1). We discuss two data collection methods; *Concealed Memory Collection (CMC)* and *Mobile Memory Games*, and two evaluation methods; *Automated Memory Validation (AMV)* and *Recall Correctness Score (RCS)*. The *recall/recognition questionnaires* are customized and discussed in the methodology section of each project independently.

5.2.1 Concealed Memory Collection

This is a method for collecting recalled memories that contains sensitive information to test the quality and quantity of recalled memories and recognized details. Prior work standards (e.g. see [158]) ask participants to freely recall and narrate memories with as many details as they can. Afterwards, researchers code the recalled content to score it against a set of predefined memory elements such as locations and emotions. This scoring provides an indication of the quality of the recalled memory. The memory elements could be used to compare several memories and draw correlations with particular interventions. For example, participants

tend to recall emotions with condition one in an experiment while they tend to recall locations in condition two.

We altered the method to enable us to generate the codes for the elements without seeing the actual content of the memory, in order to protect the privacy of our participants when recalling sensitive daily memories triggered by their lifelogs. In the **RDT** project, participants continuously lifelogged their lives through a chest-mounted camera for a month. We asked them every week to recall as many events as fast as they could within a fixed time frame. We developed this method to minimize any negative influence on their recalling capabilities if they tried to actively filter information they did not wish to share with the researchers. We also needed to address candidates' reservations and assure them that the researchers would not see either the collected photos or the collected events, to encourage participation in the study.

In the altered method, we ask participants first to recall as many events as they can and write one-sentence descriptions of each event as a memory cue to the event. The researchers do not see the collected events, but only get the number of recalled events and the time taken between the recall of each two events. Afterwards, we ask participants to recall the required memory elements about each event such as location and time while showing the event heading. The researchers also do not get this data. There are two options for the researchers: (1) getting an abstract version of the data such as number of words used or number of letters, or (2) getting an automatically-processed correctness flag after providing ground truth. An example is if the researcher knows an event happened at 8 pm and asks the participant to recall the time and they anonymously write 7 pm. The system would automatically send the researcher a predefined abstract state from the comparison such as "incorrect recall".

The advantages of this method are that the collected flags could be combined to generate custom memory metrics score and compare conditions while being mindful of participants' privacy concerns. Additionally, it reduces the legal load of data protection on the researchers as no sensitive data is stored, especially with evolving legislation about data usage and protection. Further, it saves the time of the researchers as the data is automatically processed and coded. However, the correctness validation methods used could be oversimplified in complex memories as the researchers have no access to the real data to tune it. Thus, it is mostly suited to generating Boolean flags indicating the presence of a memory element rather than the correctness of the recalled element. Additionally, it is challenging to ensure the data quality and that participants are not entering only random data. Lastly, it should not be used in scenarios where researchers would like to

gauge which memory elements are naturally recalled with particular experimental conditions. The presence of an explicit question about a memory element such as location cues participants to think about it. However, within the context of our experiment discussed later in Chapter 6, the method fulfilled our constraints.

5.2.2 Automated Memory Validation

This is a method for evaluating recalled memories that contain sensitive information to test their quality and quantity, and recognized details. It complements our data collection CMC strategy described in Section 5.2.1. In this method, the system automatically scores the participants' recalled data by comparing it to ground truth data. Ground truth data can be provided by the researchers or discretely collected from the participants. We developed this method to increase the privacy protection of our participants during the experimental phase of the **RDT** project.

In this method, participants are shown their lifelogs and the heading of the recalled event to select one photo that best represents their freely recalled event. We use the metadata of this photo such as timestamp and location to evaluate the corresponding recalled memory elements. The metadata is hidden from participants to avoid cuing them. The entire process is automated and the researchers have no access to the collected data nor the ground truth data. An example is a participant recalling that they cooked dinner at 8 pm. Afterwards, they select a photo of cooking dinner and the timestamp shows it was at 5 pm. The system would then log a flag indicating that time was recalled for this event and another flag that the time was incorrectly recalled. It is also possible to log for example, the difference between the recalled time and the objective time as it is still an abstract metric that does not expose the participant.

This method has the same advantages and disadvantages of the CMC method. Additionally, it is challenging to efficiently design the correctness heuristics without knowing the scope of the event. For example, in the previously described scenario, dinner could last for an hour from 5 to 6 pm. The participant could report that dinner was at 5 and selects a photo at 5:30. A simplified automated approach would mark the entry as incorrect, whereas a researcher who saw the dataset would conceptually fix the label.

5.2.3 Recall Correctness Score

This is a method for evaluating the quality of a recalled memory. We needed this method to compare several recalled memories across experimental conditions in the **PPMCloak** project.

In this method, we score the answers to specific questions or memory elements such as location and emotions using three correctness levels: *correct* when the answer is precise, *semi-correct* when some elements of the answer are correct (e.g. correctly describing the physical appearance of a person but not being able to provide his name when asked), and *wrong* when the answer is irrelevant. This step is inspired by prior work from Le et al. [158]. The labelling is done by two researchers and conflicts are thoroughly discussed until consensus is reached to ensure internal validity. The chosen questions should have a clear short answer to simplify the scoring process. Afterwards, we calculate the RCS metric to indicate the overall accuracy of recalled memories within a condition. RCS is a metric corresponding to the summation of weighted correctness labels. Higher values denote better recall quality. We recommend using the following weights for the correctness labels: *correct* = 2, *semi-correct* = 1, and *wrong* = 0. However, weights could be customized based on use cases.

5.2.4 Mobile Memory Games

In this section, we present the project called **PrisonerOfWords**. It is a mobile game taking a memory lab experiment to the wild. With the prevalence of ubiquitous technologies, mobile games offer promising opportunities for training and conducting in-situ memory experiments outside the lab (e.g. [131, 234, 152, 196, 37]). We find the in-the-wild gamification approach particularly promising in the context of memory research, because the collected data is a closer approximation for natural absent-mindedness[8] from interruptions while being augmented with contextual cues such as location and weather to support holistic interpretations. Mobile apparatuses like games can save lab and personnel resources [123]. Additionally, they facilitate participants' recruitment despite the high drop out rates [123], as trying an application even briefly can be sufficient to collect data for all conditions in some experiments. Moreover, they sometimes enable researchers to collect numerous encounters of rare conditions. For example, Stephan Mitroff, the designer of the *Airport Scanner* game [187],

[8] One of the memory sins described by Schacter in [226] where people suffer from natural gaps in capturing information due to lack of attention

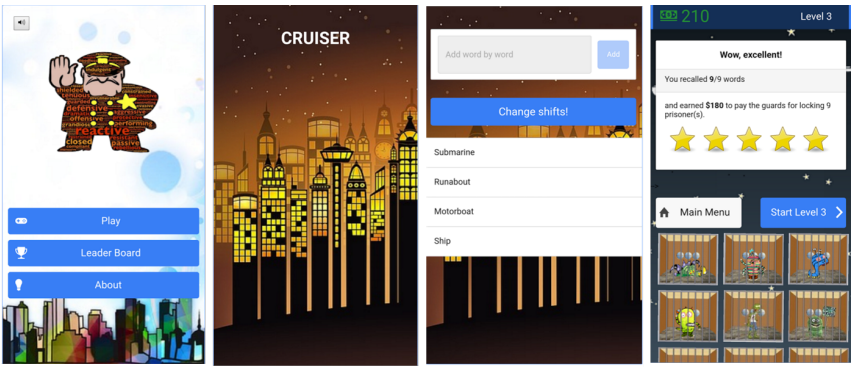

Figure 5.1: Screenshots showing the game play from the "PrisonerOfWords" memory game, replicating a part of Ward et al.'s laboratory memory experiment [263]. The player wins by recalling as many words as possible correctly from a list of words. The player sees one word at a time for one second. Next, (s)he enters as many words as they can in any order and then the results of the recall are shown. Each correct word corresponds to a credit towards getting a prisoner out of their cell.

explains: "When a target appears only 0.1% of the time, you need 1,000 trials to get a single case. Too many trials are realistically needed to assess the detection of such targets in a lab setting. Using the game, we were able to look at hundreds of cases for each of the nearly 30 rarest targets"[5]. The gamification approach also supports research replicability as a tool for ongoing data collection.

Despite the advantages of in-the-wild game deployments, transforming a laboratory memory experiment into a game is a challenging task. The interrupted incomplete nature of the in-situ data [123] adds complexity to the data analysis. This is because memory experiments traditionally employ within-subject designs with numerous conditions and trials to avoid individual differences in the recall capabilities. Additionally, human memory is prone to suggestability, cuing, and misattribution. Thus, designers have to carefully iterate and rethink game design standards for fear of accidentally introducing confounding variables to the psychological experiment. Our work here aims to raise the awareness of the HCI community about this specific problem.

We achieve this goal by reporting on the collaborative design process in an interdisciplinary team of psychologists and computer scientists to transform an existing laboratory experiment [263] into an in-the-wild mobile game apparatus. The experiment investigates the effect of a list's length on the recall. The experiment serves only as a use case to facilitate the discussion around a common

project between the computer scientists and the psychologists so that we can identify such problematic game design elements. The definition of "problematic" in this context is design decisions that can tamper with natural recall. We chose to replicate the lab experiment to gauge the validity of our design recommendations by comparing our collected data trends to existing data in literature. Our approach succeeded as we were able to reproduce the data trends from the original experiment using our mobile apparatus within a short time frame (2 weeks, n=44).

Our contribution here is twofold: (1) provide design guidelines for transforming controlled lab memory experiments into in-the-wild mobile games, and (2) replicate and validate a part of Ward et al.'s experiment [263] in the wild with conforming results to the original experiment showing that participants recall shorter lists in forward order but longer lists in backward order. Competitive scoring and smart input methods are the most challenging design elements, with potential adverse impact on the validity of the experimental data. Our work should aid game designers and psychologists to investigate human memory in natural settings without jeopardizing the quality of the collected data.

Methodology

Experimental Design We replicated an existing laboratory memory experiment as a sample use case. We opted for replication rather than designing a new experiment to establish a ground truth for the expected results and to focus on the transformation aspect rather than the experimental design aspect. Thus, we *modified* a laboratory memory experiment by Ward et al. [263] which investigated the effect of a list length on the recall quality. Ward et al. had found that as the list length increases, the natural order of recalling the words changes. Participants tend to recall short lists in forward order starting with the first word but longer lists with one of the last few words. This finding could be used to decide the preferred order in lists of information snippets. An example application in HCI is optimizing advertisement order on an ambient display to maximize memorability. Another example is ordering posts in a news feed, as similar recall patterns are observed there [197].

In the lab experiment, the independent variable was the number of words in a list (i.e. *list size*) and the dependent variables were *recall accuracy* and *recall order*. The experiment had fifteen conditions (list sizes= [1,15]). In our game, we quantized the conditions equidistantly to four discrete values (list sizes = 3,6,9,12) and reflected on the recall order only. The objective was to reduce data collection time as our main objective was reflecting on the design process rather

than replicating the experiment. We used the same word bank from the original lab experiment.

Research Method: Mobile Game Our game was a one-player game. Figure 5.1 shows a summary of the main screens in the game. The game storyline is inspired from a folkloric Iranian story book called *Shahname* (meaning "the book of kings"). In the book and the game, a hero called Rostam attempts to save the nation by rescuing the king from the demons. The player is the warden / supervisor of the prison where the king is captive. The warden authenticates the identity of the changing prison guards through passcodes formed of a list of words. The warden, i.e. our player and participant, gets a list of words representing the passcodes and has to remember them correctly afterwards, otherwise the guard misses his shift and the king along with the other prisoners can flee. Each passcode, i.e. word, corresponds to a cell with a prisoner.

Level design Each level covered all conditions as it had four lists shown in random order using round robin randomization[9]. The starting condition of different players was pseudo-randomized to cover potential combinations. Similarly, the order of conditions per player in each level was pseudo randomized to reduce order bias. Additionally, we were not able to keep each level bound to a particular list size, to avoid learning bias and order effects in the data collection.

Experimental task The participant is given a sequence of words in a list. Each word is displayed for one second similar to the laboratory experiment then disappears allowing the next word to show. After the list is finished, the player is asked to type all the words they saw in any order. The player submits the words from each list using the "change shifts" button. We do not mention the list size prior to flashing the words as it could cue the participant about the words they missed.

Input method The player types the words. However, we disable the auto-complete and the auto-correct features as these can cue the participant. For example, consider the participant remembering the word "cat" and typing it but the auto complete shows the correct word from the list that is "catch". To account for false negatives from spelling mistakes, we used a correction algorithm, namely Hamming distance algorithm with index number= 1.

[9] This is the random selection and elimination of a condition from a pool such that a condition is not repeated twice till all conditions are covered

Scoring system After the player submits a list, they get feedback about their performance. The feedback consists of: (1) amount of earned money, where every correctly recalled word corresponds to money given to the guard, (2) number of correctly recalled words compared to the list size (e.g. 8/9 words recalled correctly), and (3) number of cells with prisoners where every forgotten word corresponds to an empty cell. Figure 5.1 shows the view. The money factor[10] does not change within the same level, i.e. we do not incentivize recall of words in longer lists over shorter lists. This is to avoid tampering with the player's attention and/or recall between conditions. However, the money factor increases between levels to encourage players to continue playing and incentivize data collection. For example, a correct word would earn the player 10 points in level 1 and 40 points in level four.

$$MoneyEarned = CorrectWords * (CurrentLevel * 10)$$

Implementation and Data Collection The game was developed as a cross-platform mobile game using Ionic Framework. The data was stored locally and synchronized whenever Wifi connection was found to enable playing in internetless opportune moments. The data was modelled using a MySQL database, and was transmitted to a NodeJs Express server stored on the institute's secured servers. We collected the following information about players: gender, occupation, country, mobile type, words displayed to them, current level, words they recalled, order of words they recalled. Further implementation details can be obtained from [147].

Procedures Participants were given a consent form to complete the first time they opened the game. It explained the data we were collecting and informed them that the data was being used for research. We also collected basic demographics as explained in the previous section, such as gender, occupation, and country, and that their mobile type would be automatically logged . Afterwards, participants were allowed to play as much as they want. They were not instructed to finish a minimum number of levels nor to remove the application after a certain period. We automatically synchronized the collected data upon the availability of WiFi connection.

Participants and Recruitment We recruited participants through word of mouth, distributing the game in the researchers' social circles, snowball sampling and publicizing the game on social media. Seventy two participants played the game. We excluded 28 players who either did not complete the first level, i.e. they missed conditions or failed to recall at least one word in the first level and had no

[10] Earned money per word

Table 5.2: Summary of the serial position of the first recalled word in a list and its corresponding recall category. A list is divided into three equal partitions. FIRST indicates a forward recall list. LAST indicates a backward recall. OTHER indicates a list where a participants starts by recalling its middle element.

List size	FIRST	OTHER	LAST
3 words	1	2	3
6 words	[1,2]	[3,4]	[5,6]
9 words	[1,3]	[4,6]	[7,9]
12 words	[1,4]	[5,8]	[9,12]

further levels. This indicates that they were not playing the game but only opened to check it. Thus, we analyzed the data from 44 participants (22 males and 22 females). They came from eight countries (Iran, Bangladesh, Malaysia, Georgia, France, Germany, Sweden, and the United States of America). The mean age was 29 years old (minimum = 15 and maximum= 54). Participants submitted an average of 14.45 lists (SD= 16.6). The duration of data collection was two weeks.

Analysis Methods To validate the collected data trends, we used similar techniques from the lab experiment to analyze the game data. We divided each list into three equal intervals. Afterwards, we labelled the trials to indicate the interval of the first recalled word based on its serial position in the list. The labels were called *recall category*, and were used to understand whether participants tended to recall the lists in forward or backward order. Words from the first interval were labelled as *FIRST*, the second interval as *OTHER*, and the last interval as *LAST*. Table 5.2 summarizes the position of the first recalled word in a list and the corresponding label based on the list length. For example, a trial where the the sixth word on a 6-word list was recalled first would be labelled as LAST. However, the sixth word on a 9-word list would be labelled as OTHER.

Afterwards, we counted all the trials of a particular list size for a player. We used the total number of trials to calculate the probability of a participant recalling one of the categories. We also calculated the number of trials where participants did not recall any word.

Results: Game and Lab Results Conform

Figure 5.2 summarizes the descriptive results.The data trends indicate that participants recalled shorter lists (list size=3,6) in forward order, i.e starting with the first word. However, participants recalled longer lists (list size= 9, 12) starting in

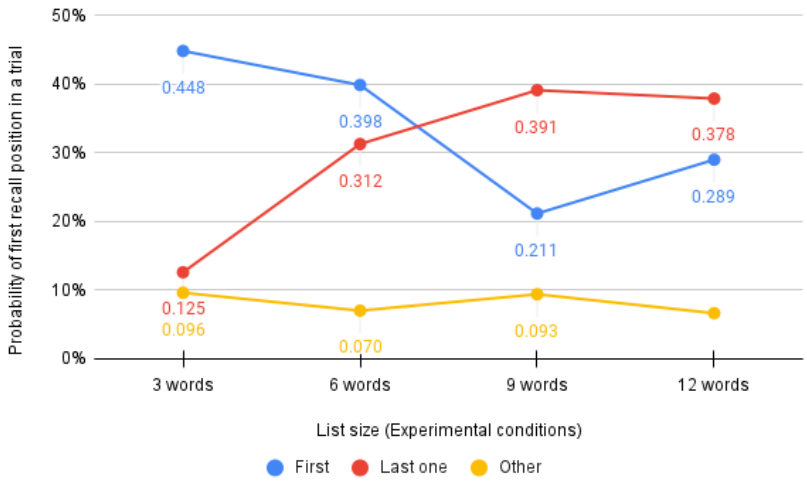

Figure 5.2: Probability of the serial position of the first recalled element in a list. This indicates whether participants are likely to recall lists from the start or the end. In accordance with the lab experiment by Ward et al. [263], participants recall shorter lists from the start (size=3 and 6). However, they recall longer lists starting from the end (size= 9 and 12).

backward order, i.e. starting with the last four words. The results are consistent with the lab experiment from Ward et al. [263].

The probabilities are calculated with respect to the total number of trials of a certain List length (LL) per participant. This implies they also include zero recall trials where participants did not recall any words. Participants recalled no words in 33.12% of the trials in with LL= 3, followed by 30.5% of the trials in LL= 9, 26.63% of the trials in LL= 12, and 22% of the trials in LL= 6. Table 5.3 summarizes the probabilities of recall after excluding the zero-recall trials. The trends are the same as the ones presented in Figure 5.2.

Lessons Learnt and Takeaways

In this section, we reflect on our experience while designing the game. The distilled points are extracted from the team's interdisciplinary arguments between psychologists and computer scientists to reach design consensus. We report on aspects that could be useful to other game designers beyond the scope of this

Table 5.3: Probability of first item recall position in a list based on its size. The probabilities are calculated after removing zero-recall trials. The trends conform with the ones presented in Figure 5.2

Recall starts with	LL=3	LL=6	LL=9	LL=12
FIRST	57.11%	45.08%	27.76%	34.37%
OTHER	13.57%	12.18%	11.17%	9.21%
LAST	18.51%	39.44%	55.82%	52.98%

particular experiment. However, we make no claims about the generalizability of the results but rather nudge the reader to notice the design problem.

Merits Can Interfere with Recall Score is a classic engagement element in game design. However, competitive reward strategies in memory apparatuses could tamper with the experimental validity of the data. Rewarding actions motivate players to remember better (e.g. [225]) and to possibly perform drastic measures to gain points. An example is the player recording then copying stimuli into the game rather than relying on their personal recall. Lack of reward systems though does not provide sufficient gratification to play the game, i.e. participate in the experiment. Thus, we have three design recommendations:

1. **Avoid rewarding secondary actions** We recommend focusing on a simple reward system for the main experimental task only rather than adding complexity to the game play through secondary rewardable actions. For example, a common method in game design to increase game complexity is to use performance time as a scoring factor. However, in some memory experiments like ours, rewarding faster responses can unnecessarily increase the error rate and impact upon the recall rate due to stress.

2. **Wisely use real-world merits** Physical merits such as vouchers and money for top-performing players can encourage fast collection of larger datasets. However, it could also negatively impact the quality of collected data if players tamper with the results or introduce drastic actions such as recording to "win". Translating real-world norms for rewarding participation time could also be problematic for data integrity. For example, rewarding the player who played the longest time could correspond to mindless submission of stimuli, i.e. low quality data.

3. **Report on the memory task** We suggest reporting the results of the memory task rather than an abstract score to enhance the player's sense of progress, achievement and contribution to the research. For example,

if the task is to remember five words and the player remembered three, the system message could be (*you remembered 3 / 5 words and earned 30 points*) rather than the earned points only.

Smart Input Methods Can Interfere with Recall Controls with predefined options like autocomplete text fields and dropdown menus are better suited for recognition rather than recall tasks as they cue the player to remember the stimuli. Thus, they tamper with the experimental data. However, using basic versions (e.g. textfield without autocomplete) jeopardizes the user experience because it is cumbersome. It also increases the error rate due to human error during data entry rather than recall failures. We recommend the following two design guidelines:

1. **Choose convenient stimuli** The complexity of the chosen stimuli such as number of stimuli and length of words or number of details in a picture should be controlled based on the input method to minimize player frustration and data entry error rates. For example, in our scenario, we specifically chose shorter words from the dataset as we used a standard text field with no prediction features.

2. **Design error recovery strategy** There are two approaches to overcome the loss of data points due to entry errors rather than memory failures. The first is to increase the error tolerance to account for cases such as typing "chiar" instead of "chair". The second is to enable editing of entries. Designers should cautiously use the latter approach. Despite reducing false negative hits, it alters stimuli recall order as players go back and forth between entries, which might not be favorable in an experiment about serial recall order, for example.

Overcome Missing Conditions through Level Design Memory experiments usually employ a within-subject design to neutralize personal recall capabilities. Conditions in a memory task usually have a natural incremental complexity such as number of stimuli. An example is if the independent variable is list size, it is harder to remember a list of 12 words compared to a list of three words. Within-subject designs are challenging in mobile deployments due to the unpredictable dropout rates [123] which can lead to excluding a large number of participants because of incomplete datasets. Levels in game design is a good tool to encourage users' engagement by giving a sense of progress and increasing game complexity. Thus, we have three design recommendations for levels to minimize incomplete datasets:

1. **Bundle conditions in a level** In simple games with shorter levels, users usually play several levels regardless of the quality of the game. Possible approaches to designing a level are (1) each level corresponds to an experimental condition and the level contains several trials (game tasks) or (2) each level corresponds to trials from several conditions. We recommend the latter where each level contains at least two trials from all conditions. The reason is to ensure that a player who plays as little as a single level in the game still provides viable analysis data. We recommend having two trials per condition in case the researchers drop the first trial as training material.

2. **Avoid leveling through condition complexity** Researchers should not map conditions' complexity to game levels as it jeopardizes the experimental validity. This is relevant where conditions are inherently ordinal such as increasing the number of words or list length. For example, we avoided matching the incremental conditions to the levels in our game where level 1 is 3-word lists then level 2 is 6-word lists. This grouping would have created a learning bias and introduced order effects to the collected data.

3. **Use step conditioning techniques** We propose mapping the levels to subsets of the conditions and collecting them incrementally, spanning the conditions' spectrum in case of ordinal conditions. For example, assume we want to conduct our experiment but on 8 list sizes $=[3,10]words$. A possible design is to have levels 1 and 2 correspond to trials with list sizes = 3, 5, 7, 9 words then levels 3 and 4 correspond to trials with list sizes = 4, 6, 8, 10 words. This ensures that at least all players submit data to coarsely-sampled conditions instead of losing all the participant's data points if they drop in the middle of a long level having the eight conditions. The conditions' order within the level should be randomized for each player to avoid order effects.

Design for Shorter Usage As we know from prior work that users use mobile apparatuses for short periods of time and it is critical to collect the required information as fast as possible [123], we recommend designing games with simple, short, and repetitive tasks. This can promote using the application in opportune moments such as waiting for a bus.

Reflections and Limitations We acknowledge that currently we do not empirically prove our design recommendations or distill the impact of each element alone on the recall. However, the conforming results between our quick game deployment and the original lab experiment after applying the proposed

guidelines is promising. Thus, our aim is to: (1) encourage designers to evaluate their game design strategies early on with psychologists in interdisciplinary teams and for both parties to mind the semantic differences in design priorities and constraints, and (2) encourage future systematic investigations quantifying the impact of such widely-used elements on experimental data. We also acknowledge that the high dropout rates might indicate that the game is not enjoyable for longer times. However, it is worth noting that the rates are lower than literature standards (e.g. ca. 40-50% in [123]). Additionally, this showcases that this might not be problematic in basic memory research as even shorter sessions provide enough data for patterns and significantly saves the time of personnel. However, for experiments requiring large numbers of trials, we recommend investing time in enhancing engagement metrics. Our findings show the feasibility of using serious games as tools for continuous validation and replication of memory experiments in natural settings.

5.3 Summary

In this chapter, we provided an overview of the 11 research types we use within this manuscript along with the 31 research methods. We contribute by presenting four extended methods to evaluate the impact of a ubiquitous-computing system on altering memories. The four methods are:

1. **Concealed Memory Collection (CMC)** for collecting memories without exposing them to researchers to protect the privacy of the participants.
2. **Automated Memory Validation (AMV)** for automatically validating collected memories without exposing their content to researchers to protect the privacy of the participants.
3. **Recall Correctness Score (RCS)** for rating the quality of remembered memories.
4. **Design guidelines for gamifying memory experiments** We used for the first research project **PrisonerOfWords** within this manuscript. In the spirit of reflective practice, we highlight the potential negative impact of designing competitive scoring systems, complex levels and smart input methods on the validity of memory experiments performed by serious games. This was achieved through replicating a lab memory study using an in-the-wild mobile game. Our results conformed with the lab experiment. Additionally,

they were collected in a short time, thus showing the feasibility of using serious games as tools for continuous validation and replication of memory experiments.

IV

Memory-Altering Use Cases

Chapter 6

Memory Augmentation via Lifelogging

In this chapter, we discuss our first use case for systems actively targeting memory augmentation through two projects: **RDT** and **LifeRewinder**. The first project **RDT** is a case study for deploying pictorial lifelogging systems for a month (N=11) and investigating the impact of summarized reviews on enhancing our intrinsic ability to remember daily events. It is an exploration medium for using a *MemAlt* pipeline to design a full-stack memory prosthetic. Additionally, we use it as an example for conducting privacy-aware memory research. Thus, we contribute by proposing methods for collecting and evaluating memories in a lab study while concealing sensitive information. The second project **LifeRewinder** is a shorter complementing project focusing on optimizing the interaction with the summary time lapses used in the first project. We envision utilizing our work in: (1) showcasing an application for the *MemAlt* pipeline as a design tool, (2) understanding the caveats of lifelogging for memory augmentation, and (3) supporting researchers with interdisciplinary research methods that capitalize on ubiquitous data collection and protect the privacy of the users.

For the remainder of the use case chapters, we will introduce the design parameters chosen for the project's system from the *MemAlt* pipeline. Afterwards, we will discuss the motivation of the project and ground it in literature. Next, we report on the prototype(s) design and the research method followed by the

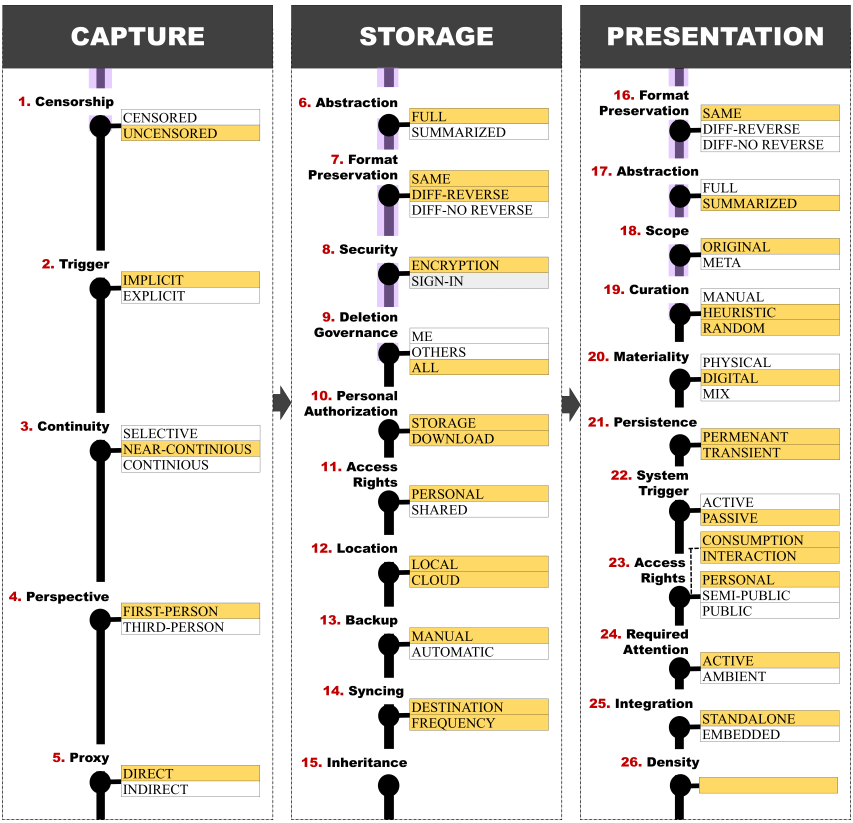

Figure 6.1: Overview on the RDT project design via the framework lens. Yellow highlights the selected parameters. Blue highlights the unspecified flexible parameters. The remaining parameters do not apply to this study.

results and the lessons learnt from that project. We conclude each chapter with an abstract version of the findings mapped to the corresponding parameters in the *MemAlt* pipeline. We use all findings to distill design guidelines at the end of this manuscript. The mapped findings in Section 6.3 answer the first part of **RQ3** about designing active MACS for memory augmentation.

Figure 6.1 summarizes the parameters we chose from the *MemAlt* pipeline to design the **RDT**'s system. This is the first example for using our pipeline as a design tool. The abbreviation PR denotes the respective framework parameter(s). The system provides uncensored near-continuous automatic capture of pictorial

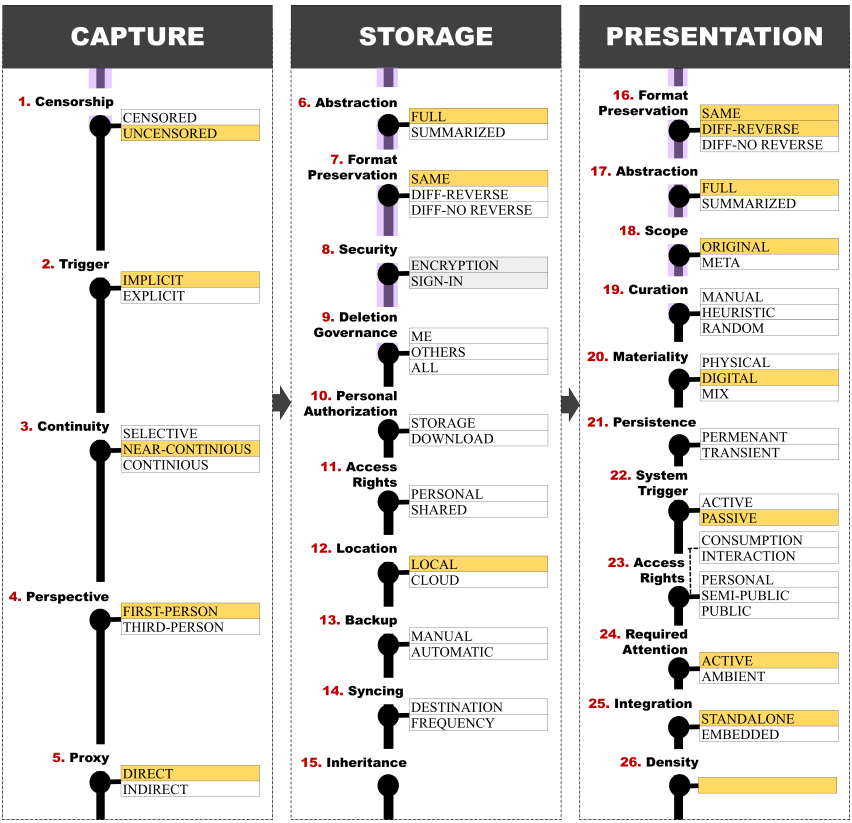

Figure 6.2: Overview on the LifeRewinder project design via the framework lens. Yellow highlights the selected parameters. Blue highlights the unspecified flexible parameters. The remaining parameters do not apply to this study. This project focuses on the interaction design rather than a full-stack system. Thus, we focused only on a subset of the parameters in the design.

lifelogs *(PR 1,2,3)*. The photos directly represent events in front of the user *(PR 4,5)*. All photos are stored, and a summarized timelapse of the photos highlighting the most important events is also automatically curated *(PR 6,7,17)*. The timelapse is created by heuristically selecting one photo per event in the day. The photo is selected randomly if all aesthetic conditions match *(PR 19)*. The photos are presented as is or in the format of a timelapse without providing meta findings about the memories *(PR 16,18)*. All content is stored in an encrypted format and is decrypted only during the presentation time. The content is only

accessible by the user at selected times in the experiment *(PR 11)*. Thus, they are not allowed to store new content or download existing content freely *(PR 10)*. All the timelapse photos are stored and processed locally on an experimental laptop only accessible by the user, to protect their privacy. The only privacy exception is the users' location data *(PR 12)*: they are required to manually synchronize their photos daily to the laptop; however, the location data is automatically captured and synchronized every night *(PR 14)*. Additionally, users back up the collected photos and timelapses once a week on a USB stick before coming to the lab session *(PR 13)*, and can only digitally see the timelapses and the comprehensive visualization of all their lifelogs when they explicitly request to see them at specific times of the experiment *(PR 20,22,24)*. The presented content only focuses on the lifelogs *(PR 25)*. The data is only available to them once (i.e. transiently) to avoid tampering with the memory experiment constraints. However, after the experiment is finished, we return their full datasets and delete all collected data unless they donate it to us *(PR 9,21)*. Data storage inheritance beyond the researchers and the users is irrelevant to the scope of the project *(PR 15)*. Only lifelog owners can access and interact with their lifelogs and timelapses *(PR 23)*. The frequency of showing the timelapses along with the design of the timelapse video use prior work findings about optimal density for memory cues *(PR 26)*.

Figure 6.2 summarizes the parameters we chose from the *MemAlt* pipeline to design the **LifeRewinder**'s system. The capturing parameters are the same as those of **RDT** *(PR 1→5)*. However, the storage model is simplified. We store the full lifelogs as photos without changing their format locally on a researcher's laptop as we provide a sample dataset from our side *(PR 6,7,12)*. We present all the raw lifelogs using two digital visualizations: a timelapse (i.e. a different format than the photos but easily reversible back to it) or as a grid of photos (same format) *(PR 16,17,18,20)*. The system models an on-demand memory vault that users have to explicitly open to look for content *(PR 22,24,26)*. We experimented with optimal speed to present the memory cues, i.e. frequency of cues at a time *(PR 26)*. The rest of the parameters are not within the scope of this project as we focus on the interaction with presented content rather than designing a full-stack standalone system *(PR 8→10,13→15,19,21,23)*.

Parts of this chapter are based on the following publication(s):

- P. Elagroudy, T. Machulla, R. Rzayev, T. Dingler, M. Funk, A. Schmidt, G. Ward, and S. Clinch. Impact of reviewing lifelogging photos on recalling episodic memories. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing, UbiComp Adjunct 2016, Heidelberg, Germany, September 12-16, 2016*, pages 1014–1019. ACM, 2016
- P. Elagroudy, C. Soliman, S. Abdennadher, and A. Schmidt. Liferewinder: speed reviewing of lifelogs using tangibles. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays, PerDis 2019, Palermo, Italy, June 12-14, 2019*, pages 30:1–30:2. ACM, 2019

6.1 In-Situ Lifelogging Case Study

In this section, we present the **RDT** project. Photos are among the most common cues to augment human memory. The downside of the abundant affordable solutions capturing and sharing photos is the cripplingly large datasets left unused by time. This creates a need to summarize and review relevant photos to revive important events. The research community actively addressed this research gap to automate the selection and presentation of important photos (e.g. key photos selection [160, 70], summarized presentations [101, 43]). The results were adopted and complemented by commercial lifelogging platforms providing a user experience that supports reminiscence and reflection. For example, Facebook and Google photos prompt reviewing of photos taken on the same day in previous years . Similarly, the narrative clip[11] offers an on-demand time lapse video of the photos taken within a day.

Despite the popularity and abundance of photo-reviewing tools, there is limited in-situ research showing the impact of such daily reviews on shaping the users' episodic memory (e.g. Sense cam studies like [90, 227]). To address this research gap, we designed a longitudinal case study of pictorial lifelogging in the wild for a month (N=11). We designed the experiment with three objectives in mind: (1) investigating the effect of regular reviewing of egocentric lifelogs on the formation and retrieval of autobiographic memories, (2) understanding challenges and

[11] A clip-on camera and platform for near-continuous pictorial lifelogging

opportunities of lifelogging as a niche application, and (3) developing a privacy-aware memory examination protocol using lifelogs, that enables researchers to validate the recall quality without requiring participants to share sensitive information about themselves or bystanders. Our contribution here is multi-faceted:

1. Developing two prototypes
   (a) *Review-Me*: A prototype for reviewing lifelogs in the wild using time lapse videos.
   (b) *Life-Dome*: A prototype for sequentially reviewing large datasets of pictorial lifelogs (see Figure 6.3). In our case study we used it to review one week's worth of photos (ca. 4k photos at a glance and ca. 12k photos in a week).
2. Developing two research methods
   (a) *Concealed Memory Collection (CMC)*: A method for collecting memories privately in an examination session (see Section 5.2.1 and 6.1.2).
   (b) *Automated Memory Validation (AMV)*: A privacy-aware method to automatically validate the quality of recalled memories (see Section 5.2.2 and 6.1.2).
3. Exploring the impact of daily reviews on the autobiographical memory in real-world scenarios.
4. Reflecting on the users' challenges in using lifelogging as a niche application as well as highlighting the challenges in conducting such experiments.

Our work supports the research community in conducting privacy-aware memory research while offering a step forward to the adoption of memory altering ubiquitous-computing systems.

6.1.1 Prototype Designs: *Review-Me* & *Life-Dome*

We present here the concept and implementation of two prototypes: *Review-Me* and *Life-Dome*. "Review-Me" is the system we gave our participants to capture and store their pictorial lifelogs then review their daily activities from summarized timelapses. "Life-Dome" is a privacy-aware setup we used in the laboratory to

Figure 6.3: Setup showing the *Life-Dome* prototype. It consists of six 50-inch screens, each presenting a day in the life of our participants. Each entry in the grid is a photo captured every 30 seconds automatically by a clip-on camera. Each participant's consent was acquired to publish the data. The screens show a maximum of 4218 photos at a glance (703 photos per screen).

review all the weekly lifelogs at a glance and validate the recalled memories. We will discuss the technical architecture of the prototypes later in Section 6.1.3 as a part of the experimental setup.

Reviewing Types We introduce two types of reviewing lifelogs that we call *parallel reviewing* and *sequential reviewing*. *Parallel reviewing* refers to getting an overview about a person's activity through several photos at a time. An example of this is the viewing the weekly lifelogs using the "Life-Dome" prototype. This type of reviewing is better suited for viewing larger datasets and getting a holistic overview on a lifelog. *Sequential reviewing* on the other hand refers to viewing the photos consecutively. An example is viewing the key photos in the timelapse daily videos in the "Review-Me" prototype. This allows the user to focus on the details of a photo; however, regular navigation within larger datasets is a tedious and overwhelming task.

In-the-wild Prototype: Review-Me

We built a summarization toolbox for windows machines (see Figure 6.4). The system is composed of a laptop, a Narrative-clip wearable camera, a commercial mobile GPS logging application called "GPSLogger", and a USB stick. The

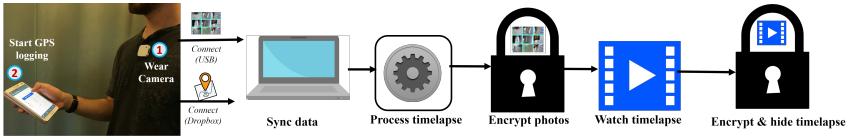

Figure 6.4: Setup showing the *Review-Me* prototype setup. We deployed this setup for one month with our participants to capture, store and present summarized versions of their pictorial lifelogs as timelapses. The timelapses were the memory aid showing a summary of their daily activities. The system is composed of a clip-on near-continuous capturing camera, a laptop acting as a processing unit and an external GPS tracker to aid in identifying the events of the day.

camera and the GPS application act as capturing devices, while the laptop is a local storage and processing unit to protect the privacy of our participants.

The camera automatically captures a photo every 30 seconds, rendering ca. 1680 photos per day[12]. The camera stops capturing the photos if flipped to face a surface. The GPS logger continuously captures the location to assist in clustering the events in the photos for the post processing of the time lapse. External GPS is used to overcome the proprietary location format of the camera and to avoid uploading the pictures to a narrative cloud service to preserve the privacy of our participants. The GPS coordinates are automatically synced to a private cloud service account[13] installed on the laptop.

The captured photos are synchronized every night and processed locally on the laptop to generate video summaries overnight. The synchronization process is manually triggered by the user and takes around 15 minutes. The photos and the timelapse are not synchronized to any external cloud service. After initial synchronization, the photos are encrypted then the original synchronization is deleted. The photos can only be decrypted later by a tool on the researchers' side. The encryption purpose is two-fold: (1) to prevent the user from reviewing the photos to avoid learning effects, and (2) to secure the data on the user's computer.

The timelapse has one key photo per event in the day. The time lapse can only be viewed once then it is also encrypted and hidden from the user. The selection and presentation of the key photos are based on the requirements and algorithms described in [158]. Events are clustered by visual similarity of the photos within the same time frame and location. Key photos are selected using aesthetic heuristics such as least blurry, well-lit. Each photo is shown for three seconds to

[12] Assuming continuous logging of an average time = 14 hours (8 am to 10 pm)

[13] We used Drop Box service

allow for reflection and reminiscence. The timelapse duration is approximately 2-3 minutes of key pictures depending on the number of events in the day. This is approximately 40 photos for a two-minute timelapse summarizing 1680 photos.

Lab Prototype: Life-Dome

In this section, we describe the conceptual design for a system used to reflect and review large datasets of lifelogs and/or for anonymously collecting and validating memories in an experimental session in a privacy-aware manner (see Figure 6.3).

It consists of six large displays arranged in a half circle surrounding the subject. Each screen represents a day of the week arranged in ascending order from left to right (Sunday to Friday for example). We used six screens only as we had a one-day break every week in our experimental design. However, the system could be extended to add another screen for the seventh day. Each screen was built using a 50-inch TV. The participant sits in the middle of the dome at a distance allowing them to scan all screens at once (i.e. parallel reviewing) and is allowed to walk around to get a closer look (i.e. selective reviewing).

Visualizing the Lifelogs The photos of a day are displayed as sequential thumbnails in a grid format. All photos are displayed in the original temporal order without filtration nor editing. One page of a single screen (i.e. day) shows a maximum of 703 photos (19 columns * 37 rows). We chose the size of the thumbnails heuristically through pilot experiments on four colleagues to reduce visual overload. The photos by design are small enough to mask details to avoid mental fatigue and show the overall structure of events in the day through visual similarity. However, they are large enough for the viewer to perceive the salient features such as number of people and prominent colors to facilitate the search process. The visualization supports pagination to show the rest of the day. A day on average comprises 2.3 pages[14].

The grid rows are numbered to facilitate limiting the search space if the participant knows the approximate temporal order of the searched event. Additionally, the numbers give an intrinsic sense of the time consumed doing a particular activity. We deliberately avoided: (1) grouping photos into events, (2) displaying the timestamps of the photos, or (3) grouping photos with other semantic features such as location or salient colors. Such practices could tamper with the participant's recall of events by cuing them, and jeopardize the experimental protocol.

[14] This is assuming a 14-hour continuous-logging day. A 24-hour day requires 4 pages.

Interacting with the Lifelogs Participants can maximize a particular photo to take a closer look. They interacted with the photos through an enlarged mouse pointer using a wireless keyboard and mouse. The wireless property is a design decision to enable traversing large distances on the table. We implemented a "find my mouse" feature as we know from the pilot studies that participants frequently lost their cursor. Participants submitted a particular photo by double clicking on it, then confirming the choice in a dialogue box to avoid false selections.

6.1.2 Methodology

The aim of our study is to investigate and evaluate a tool that supports the formation and preservation of autobiographic memories. We hypothesize that reviewing daily timelapses of pictorial lifelogs can be used as a memory aid to improve the recall quality of past events.

Research Method: Lab Study

Study Design We conducted a 2X2 within-subject design experiment investigating the impact of reviewing lifelogs on the recall quality of autobiographical memories. We had one independent variable, *usage of reviews* with two conditions: show reviews (C1) and the baseline as hide reviews (C2), and one effect variable: *relevance of events to reviews*, calculated post-hoc with two conditions: event relevant to review (C3) and event irrelevant to review (C4). Our dependent variable was the number of recalled events. The experimental block of the study was one week. The week was divided to three consecutive days per condition followed by a break day, then a memory evaluation lab session on the eighth day. The timelapse of a day was always shown the following day to encourage maximum logging time and to overcome technological limitations in required processing time[15]. The photos were not accessible during the weekdays to eliminate learning effects. All key photos were shown for an equal amount of time. The experiment lasted for four weeks with a total of four lab sessions and twelve reviewing timelapse sessions. We counterbalanced the order of the conditions between participants and between the blocks.

Lab Session Flow The objective of the lab session was to collect free-recall events and examine their quantity and quality while preserving the privacy of the

[15] The required time to process and generate the timelapse was around four hours on a core i5 laptop. Thus, showing the timelapse on the same day required the participant to plan their sleeping schedule to account for synchronization and generation of the timelapse.

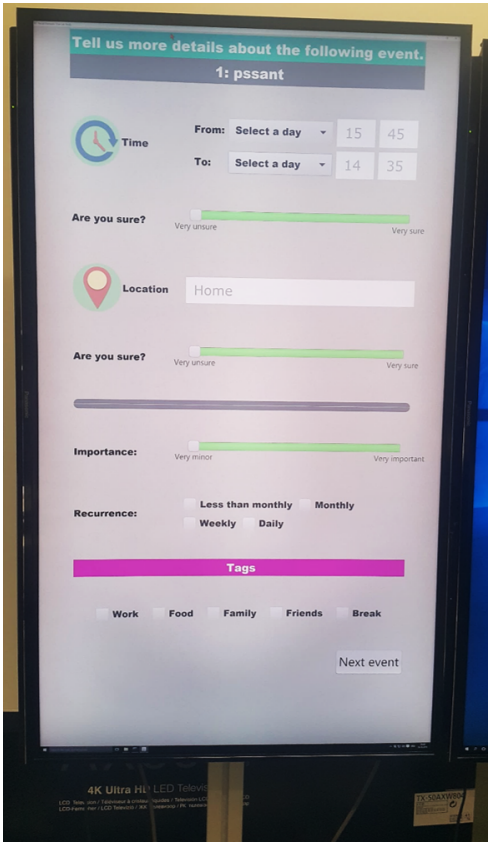

Figure 6.5: A screenshot showing the second phase of the lab session for memory examination. In this phase, the participant informs us about further details regarding the recalled event such as location and time.

participant. *A recalled event* refers to an incident freely recalled by the participant within a single day. The granularity of the incident was left for the participant to define. For example, a participant could recall "eating dinner" as an event but "eating pizza" then "eating pie" as two separate events. Similarly, "brushing my teeth" would not be a valid event without mentally specifying the day. The lab session comprised four phases. The first two, i.e. free recall of events then cued recall of event details, were an implementation of the CMC method (see Section 5.2.1). The last two phases, i.e. matching the event to a photo and validating

the event, were an implementation of the AMV method (see Section 5.2.2). The phases were carried out as follows:

1. **Recall events:** The participant is asked to remember as many events from the past week as possible. Each event is noted down in a few words (typically 1-3 words) as a cue for the participant. The phase lasts for four minutes divided equally into eight iterations. This time period is based on prior research by Moreton et al. showing that the rate of spontaneous recall drops to about one item every 30 seconds after this time period [190]. The pressure encourages participants not to spend a long time dwelling on a single event. Each iteration is marked with a beep. We only log the number of characters in an event as an indicator for the researcher in the analysis.

2. **Recall cued event details:** The participant provides additional details about date, time and location of each recalled event (see Figure 6.5). The selected details are inspired by the parameters used in prior work to evaluate the quality of free recall in interviews (e.g. [158]). Additionally, they report on the importance of the event and how recurrent it is. There are no time constraints for this phase. We log the recalled time. However, we only log the location as a number of characters, like the event content, to conceal it.

3. **Match the event to a lifelog photo:** The participant is shown the previous week's lifelogs using the "Life-Dome" prototype (see Section 6.1.1). They are asked to identify one image that best describes each recalled event. We show them the event description they submitted in the first phase as a cue. We call this photo the *reminder or representative photo*. There are no time constraints for this phase.

4. **Validate the events' details:** Using the selected lifelog photo as a cue, the participant reports any incorrectly reported time and location details in phase two. They indicate the relevance of the event to the selected subset of key photos from the timelapse. We only show two key photos representing the closest prior and following photo to the reminder photo. It is worth noting that we show the key photos from timelapses in both review and no-review days, i.e. not all key photos have been seen before by the participant. This step is to gauge the quality of the selection algorithm. There are no time constraints for this phase.

We also conducted two semi-structured interviews, in the first and fourth lab session, to collect qualitative information about user expectations from the technology, the attitudes towards privacy and usage of data, feedback about the deployed system, and general challenges and opportunities for using lifelogging.

Procedures

We provided an orientation session for the participants about their legal and ethical rights as well as the co-participants' and strangers' rights during during photo captures. The study was conducted prior to the General Data Protection Regulation law in the European Union. Thus, we had to explicitly encourage participants to practice mindful behaviour while wearing the camera. In the session, we gave the participants a bag containing their hardware for the "Review-Me" prototype; a laptop, a wearable camera, a USB drive and respective chargers. Additionally, we installed a GPS tracker on their personal mobiles. The session lasted for approximately one hour.

We instructed the participants to wear the camera and activate the GPS logger at all times except in private moments and during sleep. We left the definition of private moments to the discretion of the participants. Participants operated the "Review-Me" prototype on their own every day during the week. In the morning, they would put on the camera and open their GPS tracker. Before sleeping, they would synchronize the photos to the laptop and charge the camera. Timelapses were created for all days. The system would prompt them to watch a timelapse summarizing the previous day only if they were in the experimental block of the first condition. We disabled seeking in the timelapse to ensure that participants viewed the timelapse to the end only once. At the end of the week, participants copied the encrypted photos to the USB stick.

After every experimental block, participants came to an individual lab session on the eighth day. They would be greeted by the one researcher. The weekly photos would be copied and decrypted on the lab machine running the "Life-Dome" prototype, with the researcher operating the "Life-Dome" which opens to a blank empty screen. The initial table and chair location were kept constant throughout lab sessions. Afterwards, the researcher would move to face the back of the screens with the participant sitting facing the setup, thus ensuring that only the participant could see the photos and the recalled events. The participant would press ENTER to start the experimental session, and was encouraged to make meta comments during the third phase. The researcher would be taking notes of comments.

After the participant finished the four experimental phases, the setup also showed a blank page to allow the researcher to move freely in the lab. The data was deleted from the lab computer and the USB stick under the participant's supervision. In the first and fourth lab session, the researcher also conducted a semi-structured interview, which with the participant's consent, was audio recorded.

At the end of the last lab session, the researcher would thank the participant, take back the hardware, and provide a monetary compensation for the participation in the study. Afterwards, the researcher would ask the participant if they would like to keep a copy of their one-month lifelogs. If they wished to, the researcher would decrypt the dataset on the laptop used for the "Review Me" prototype and transfer the data to the participant's chosen storage device. The researcher would also ask the participant if they were willing to disclose their collected photos to the research team for further analysis, explicitly explaining that this was completely voluntary and would not impact on the compensation. If they agreed to this, they were encouraged to review their dataset and remove sensitive information, and were asked to signed another release consent form highlighting the acceptable usage level of data[16].

Participants and Recruitment

We recruited 11 participants (5 females, 6 males) through Facebook groups of university students and generic expat groups. The mean age of participants was 24.63 years ($min = 19, max = 28, std = 3.38$). We included seven nationalities from Europe, Asia and the Middle East to diversify the cultural background of the participants. We excluded participants with full time jobs to eliminate professional confidentiality breaches. We reimbursed the participants 200 € for their participation, in addition to their captured datasets (photos, GPS data and timelapses). On average, the participants spent 20-30 minutes daily doing tasks using the "Review-Me" to synchronize the data, charge the devices, and view the timelapses. A lab session lasted for two hours on average and interviews lasted for approximately extra 30 minutes.

Analysis Methods

Impact of Reviews on Recall In this section, we show how we analyzed a snippet of the collected data without exposing its content to protect the privacy of the users. This an example application for applying AMV and could easily be extended to include further parameters.

We first filtered the data by dropping the first session from all participants to be on the safe side and avoid skews related to novelty effect / lack of training. Thus, we analyzed the data from three experimental sessions covering a duration of three weeks. We also removed all events that participants reported were spanning

[16] Anonymous analysis and/or usage in publications.

several days (38 events) or where their start time was older than their end time (15 events). We analyzed a total of 737 events.

We post-processed the data to calculate two metrics for each of the two conditions (C1: show reviews "review days" and C2: hide reviews "no review days") thus:

1. **Number of recalled events** This metric is used to quantify the recall of the participants to understand the impact of the reviews on augmenting their memory. We count the total number of free recall events that were recalled from all the review days of the week and all the no-review days of the week. We label the event by comparing the timestamp of the representative photo[17] to the experimental schedule of review and no-review days for each participant. For example, if the representative photo was taken on 15/07/2021, we check the condition presented on 15/07/2021 in the participant's schedule and label the event with it. Afterwards, we count the total number of events across the full duration of the experiment for each condition.

2. **Number of relevant photos** In this metric, we label the events based on their relation with the selected key photos in the reviews. This is mainly used to evaluate the quality of the algorithm and to check if there is memory recall clustering. For each event, we mark it with one of five labels:

   (a) **NO-REP-PHOTO** : Participant did not find any matching representative photo

   (b) **NO-KP** : Participant did not think any of the closest key photos from the review were relevant

   (c) **KP-BEFORE** : Event is more relevant to the key photo before the representative photo

   (d) **KP-AFTER** : Event is more relevant to the key photo after the representative photo

   (e) **KP-BOTH** : Event has equal relevance to both key photos

   To differentiate between KP-BEFORE, KP-AFTER, and KP-BOTH labels, we look at the percentage of relevance for both key photos if they are above 50% and select the highest of them. Otherwise, if the relevance of both key photos is below 50%, it is marked as non relevant (label 2). An example is if an event is 60% relevant to the key photo before and 70% relevant to

[17] The photo they selected from "Life Dome" to best represent their event.

the key photo after, it is labelled as Label 4, relevant to key photo after. Next, we count all relevant events to the reviews by counting the number of events labeled as KP-BEFORE, KP-AFTER, and KP-BOTH. We count the number of irrelevant events by counting NO-REP-PHOTO and NO-KP.

We applied two way repeated measures ANOVA on both metrics to evaluate the (1) impact of the reviews on recall, and (2) the quality of the selection algorithm.

Attitudes towards lifelogging We analyzed the semi-structured interviews to determine the initial user attitudes towards lifelogging from the first week interviews. We distilled the altered attitudes from the fourth week interviews. One researcher analyzed all the interviews using inductive coding. The focus was values coding to find patterns in using lifelogs, and common problems with the experience. The themes were further discussed with another two researchers on the team who were exposed to a subset of the interviews. We chose in-vivo coding in the reporting to convey the powerful perspective of our participants. The researchers also discussed the observations collected from interacting with the participants and their background stories that were not officially reported in the interviews, along with our experiences from other experiments. Thus, we also used narrative ethnography to better understand the qualitative data.

6.1.3 System Architecture

In this section, we describe the architecture of the full experiment. This is a full stack implementation for an external memory prosthetic using the *MemAlt* pipeline. Figure 6.6 gives an overview on the components of our system. We numbered the stages using green circles to simplify referencing them. Stages 1 to 4 constitute the work flow for "Review-Me" prototype. Stages 6 and 8 build the reviewing component for the lifelogs. Stages 7, 9, and 10 correspond to the implementation of the CMC method. The AMV method is implemented in Stages 8 and 9. The system is implemented using JavaFx, the timelapse selection using C++, and the databases using SQL. We describe below the stages.

1. **Synchronize data** The participant manually connects the camera to synchronize the lifelogs to the hidden Narrative clip folder stored locally on their PC. The GPS data is automatically synchronized from the mobile to the Dropbox folder upon the availability of internet.

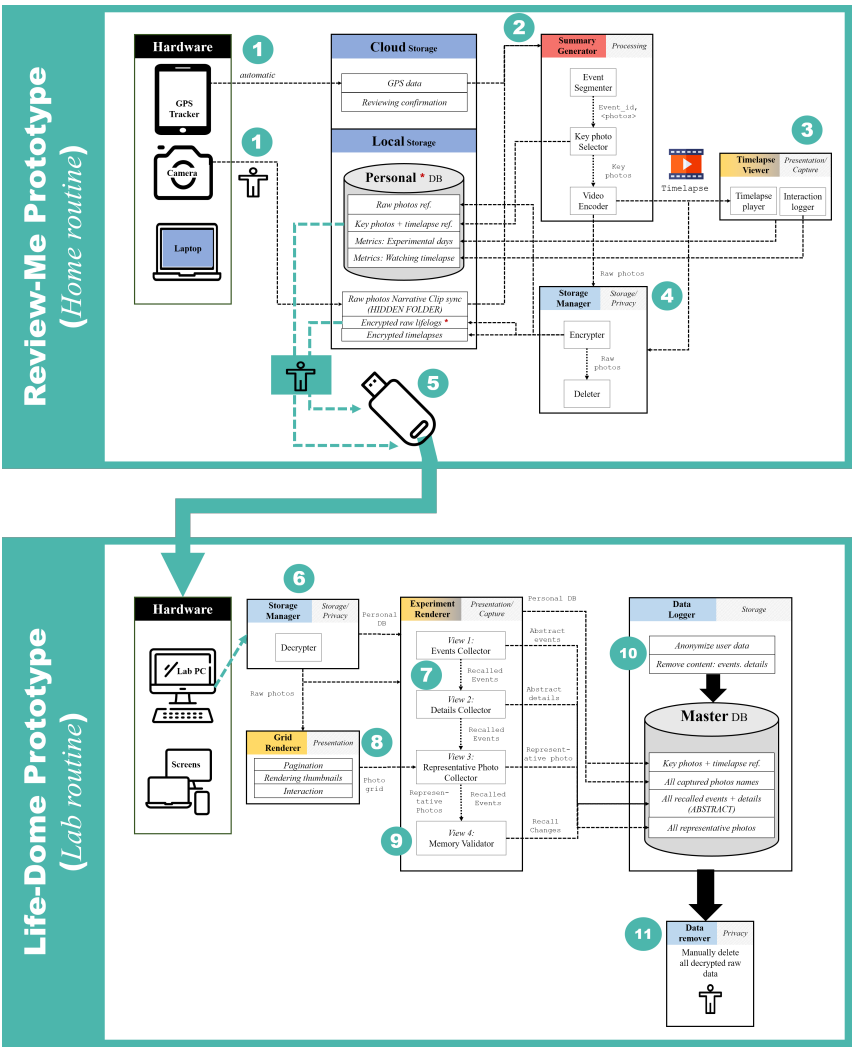

Figure 6.6: Overview on the system architecture of our experiment, including the implementation blocks for "Review-Me" and "Life-Dome" prototypes. Grey pattern shows the *MemAlt* pipeline layer of the component. The layers are color coded using the component's background. Dotted lines present input and output data of the component. Person icon refers to manual syncing. All icons are acquired from `www.flaticon.com` and are free for personal or commercial use. The Timelapse icon is made by "Good Ware", Screens icon is made by "Srip", USB icon made by "Catkuro", Person icon made by "Those icons", and the rest made by "Freepik".

2. **Generate the timelapse** This takes place in the (Summary Generator) software component. The participant starts our software. The software automatically fetches the photos from the hidden Narrative Clip folder and analyzes them. Several descriptors are extracted to indicate the photo quality such as blurriness and color salience. GPS data along with temporal and content resemblance are used to divide the photos into events in the (Event Segmenter). Afterwards, one photo is selected to best represent the event. The selected photo has the best aesthetic descriptors from the event. Those parts are implemented using C++. Next, the video is compiled using a Java Wrapper. Further technical details can be obtained from [157].

3. **Show the timelapse** The next day when the user opens the laptop, the system prompts them to watch the timelapse if it is a review day. The timelapse is displayed using the (Timelapse player) component. Interaction metrics such as when the timelapse was opened, when it was closed and whether the user finished it or not are logged using the (Interaction Logger) component. The metrics and experimental condition are logged in the personal local database.

4. **Secure the data** The timelapse and the raw photos after generating the timelapse are passed to the (Storage Manager) component to be encoded. Afterwards, the original data is deleted. The names of the raw photos as well as the key photos and their respective timelapse ID are logged in the personal local database. The names are the timestamp of the photo. The encrypted photos and the timelapses are stored locally on the computer.

5. **Synchronize lab session data** The participant manually copies the encrypted lifelogs and the personal database to a USB stick that will be used in the lab session.

6. **Decrypt the weekly dataset** In the lab session, the USB content is copied to the lab PC and decrypted.

7. **Collect the recalled events** The experimental software is started. The views correspond to the stages described in Section 6.1.2. The first view collects the events in an empty dark notepad-like view. Only audio timers are used to avoid distracting the participant. The second view collects further information about the event (see Figure 6.5).

8. **Render the comprehensive lifelogs** The decrypted photos are loaded into the software and a copy of smaller size equals to the thumbnail size is created. This is done to reduce the computational overload of the system.

Table 6.1: Summary of average relevant recalled events to the video summaries

Review Usage / Relevance	Relevant events	Irrelevant events
Review day	18.818 (SD= 13.037)	7.909 (SD= 5.049)
No-review day	15.909 (SD= 6.906)	6.273 (SD= 5.002)

Upon demand for a certain photo, the original high quality photo is loaded and expanded. The rendered view is passed to the (View 3) component to link it to the recalled events and activate the data logger. Figure 6.3 shows what the view looks like.

9. **Validate the memories** We compare the timestamp of the representative photo with the timestamps of the key photos in the timelapse generated on the same day of the photo. We get the closest matching before and after key photos and ask participants about them. Additionally, we let them review their answers from View 2 using the photo they selected in View 3 and log all the details into a Master database.

10. **Synchronize with master database** The master database is hosted on the university servers. We also synchronize all the details from the personal local database to it after anonymizing the content. The personal database contains only pointers to the data such as timestamps. However, it does not contain any references to the raw captured or processed data.

11. **Delete all private data** In the last stage, the researcher under the supervision of the participant deletes all the encrypted and decrypted raw data folders on the lab computer or the USB stick.

6.1.4 Results

We differentiate between co-participants and bystanders. *Co-participants* refer to individuals having frequent contact with our participants such as flatmates or colleagues. *Bystanders* refer to strangers in the capturing vicinity of the camera, such as other commuters on public transport or other customers in a supermarket. Our analysis mainly focuses on the attitude of the co-participants as this highly impacts on the experience and the participants' inclination to adopt the technology.

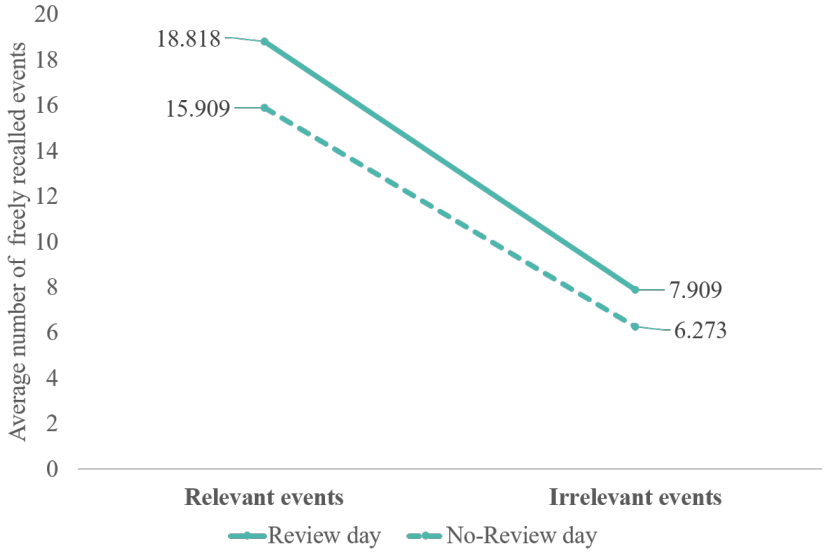

Figure 6.7: Freely recalled events were relevant to the key photos in the review summaries regardless if the review was shown to users or not. This indicates the high quality of algorithm selection for events recalled by participants.

Impact of Reviews on Memory Recall

The analysis presented here only covers a snippet of the analysis done on our data highlighting the relevant parts of this thesis. Thus, the reader will find earlier reported collected parameters that are not used here for the sake of completeness.

We applied two way repeated measures ANOVA on the following two variables: *usage of reviews* (conditions: review day, no-review day), and *relevance of recalled events to key photos* (conditions: relevant, not relevant). The assumption of sphericity was met as we have two levels.

There were no significant interaction effects between the usage of reviews and the relevance of recalled events ($F(1,10) = 0.174, P = .685 > .005, \eta_p^2 = 0.017$). This implies that the events on the review days were not more clustered around the review videos.

There was no significant main effect of the usage of reviews on the number of recalled events ($F(1,10) = 1.527, P = .245 > .005, \eta_p^2 = 0.132$). This implies that we did not find a difference in the amount of recall because of the introduced

reviews. Thus, there were no measurable memory augmentation effects because of the reviews.

One possibility explaining this is the poor selection of photos in the review videos. However, this possibility was rejected because we found a statistically significant effect of the relevance to the key photos on the number of freely recalled events ($F(1,10) = 8.921, P = .01 < .005, \eta_p^2 = 0.471$). Thus, we found that the number of relevant events to the reviews is always higher regardless of whether the users were actually exposed to the reviews or not. Using descriptive statistics, Figure 6.7 and Table 6.1 summarizes the relevance result. The number of events relevant to the key photos in a review day is significantly higher by 137% than the number of irrelevant events to the key photos. On the other hand, the number of events relevant to the key photos in a no-review day is significantly higher by 153.6% than the number of irrelevant events to the key photos. This implies that the selection quality of the algorithm for relevant key photos representing the events in the user's day is high. It is worth noting that this did not conform with the subjective evaluations of the participants about the quality of the reviews in the interviews as they sometimes found the photos irrelevant. Thus, this indicates that the subjective perception of the algorithm's utility can highly differ from its objective utility. Another angle to consider is that the algorithm is able to partially predict what the participants will remember rather than enhancing their recall.

Attitudes towards Capturing Lifelogs

In this section, we discuss how the participants and the co-participants perceived the capturing device (wearable camera) and the captured data. Participants mainly focused in their comments on the physical comfort of wearing the camera for longer periods. However, they were relaxed about the captured data even if it contained sensitive information. On the other hand, participants' reports about co-participants reactions were focused on the captured data. We discuss both perspectives in detail below, highlighting the changes in attitude about lifelogging of both groups within the course of the experiment.

Participants' Perspective: Camera Comfortability They shaped their daily activities in the beginning around wearing the camera to ensure the quality of the photos. However, as the experiment progressed, it became a part of their daily routine.

Started with fear of device and data loss At the beginning of the experiment, participants were tense about the presence of the camera. Two main reasons were: (1) fear of losing it due to its small size and ease of dropping it

without noticing, and (2) fear of covering it, which disrupts the capturing via unintentional movements or body parts. For example, **P10** narrates while on a bus trip *"I started shouting: "I lost the camera", and everyone started looking for it. After a few minutes, I realized that it was still in my shirt. It fell because it was so loose"*. Similarly, **P7** explained *" maybe you don't have to think about it, but you have to take care that the camera is not covered"*.

Ended as daily routine and a regular accessory The participants' attitudes changed towards the end of the experiment. They considered the camera a part of their daily routine and started describing it as an external body part **P11** or another accessory (such as a mobile phone **P10** or part of dress **P5**). For example, **P8** said that *"With the passing of time, I just forgot about it, and I did normal stuff as if the camera wasn't with me"*.

Limited consideration to user's physique Despite getting used to the camera over time, participants experienced difficulties in camera positioning related to their physique. Common problems were associated with: short height, large bust, and the need to adapt wardrobe and hair style. Short participants often missed capturing meaningful photos including the faces of their co-participants and bystanders. For example, **P10** explains *"I am too short. When I am standing really close to some tall friends, I am not capturing them. I capture only clothes and jackets"*. Similarly, larger busts direct the capturing angle to the ceiling rather than the surrounding when the clip was chest-mounted. For example, **P3** explains *"It wasn't good for the pictures as I was moving a lot and my chest is not plain"*. Similarly, the camera is not stable on wider necklines and is often covered by the long hair of our participants. Some participants reacted negatively to the required changes refusing to adopt the technology. For example, **P3** stated *"It is better not to have it [camera] for me, so I do not change clothes"*. They explained *"Winter happened, rain and cold happened and I wanted to cover my chest but I had the camera all the time and I was annoyed"*. However, some participants positively perceived the change as an opportunity to renovate their wardrobe. For example, **P10** explains *"There are a lot of dresses I did not wear in the last 4 weeks, round necks and high necks. But I bought new clothes for this. I was so happy about it. I bought new shirts and got really excited"*. The problems were more prominent and more widely reported by female participants.

Co-participants Perspective: Camera Awareness There was a conflict regarding the acceptability of capturing the surroundings and sensitive situations

between the participants and co-participants. Participants were generally relaxed about accidental capture. For example, **P11** explains *"A couple of times I forgot to take it off while going to the toilet and I remembered only when I was back. Then I thought, okay if no one else is seeing it then it's okay"*. Similarly, another participant reported that they forgot about the camera while checking their online banking portal. However, they did not mind afterwards when they realized as it was hard to find the exact photos.

Started with agitation from capturing Co-participants, however, were uncomfortable around the camera especially at the beginning of the experiment. However, the participants could not easily empathize with their concerns. For example, **P11** told us about a dinner in a friend's house *"... they say thing that because they are not wearing proper clothes and not combing their hair. So, somehow the pictures should not be recorded and then, I explained to them that no one is going to see this pictures except me who is already seeing you in this dress. So it's okay"*. Such conflict in perspective resulted in discord several times during the course of the experiment with several participants. We postulate that the co-participants' rejection is aggravated in the beginning because of camera disguise as they do not realize there is a camera in their surroundings. For example, some thought it was a medical device or an MP3 player. Some camera manufacturers overcome this problem by designing brightly colored cameras or by having flickering lights indicating capture mode. Some of our cameras were brightly colored. However, this seemed to cue unwelcome interaction from the co-participants and bystanders with the participants. For example, **P9** said *"My friends in class wanted to ask me out of curiosity because okay the color is orange and I didn't have any orange so it was very colorful"*. Similarly, **P8** commented *"sometimes the people for example in an U-bahn*[18] *looked at me with a strange face, and they looked directly to the camera"*.

Ended with integration in social interaction Co-participants' acceptance of the camera increased over the course of our experiment. They started to positively interact with the camera and treat it as an active entity. For example, **P1** 's friends tried to *"pose for the camera"*. Similarly, **P9** said *"They [his co-participants] say hi to the camera sometimes. They also touch it saying take my pictures please"*. However, new social power dynamics emerged within groups where co-participants remained conservative about the camera usage. For example, **P11** said regarding the same group who

[18] Name of transportation metro in Germany

refused the recording in the beginning *"I took it [the camera] off for like 30 minutes, because I was trying to gauge their [co-participant's] response. If my friend sounds serious, I take it off but put it on again later"*.

Attitudes towards Storing Lifelogs

In this section, we highlight the impact of the data's storage location on the participants' acceptability of joining the research experiment. Afterwards, we discuss the user preferences to retain the lifelogs for longer periods.

Local personal storage during experiment In the beginning of the experiment, participants were concerned about the storage location of their lifelogs and the accessibility of the researchers and/or other third party to it. Only 27% (3/11 participants) stated they would have participated in the experiment regardless of the storage location, while the rest praised our design decision for storing the data locally on a device only accessible by the participant. They also commented that they would not accept the photos being stored in the cloud even if it was on the university secure server. Interestingly, the conservative attitude changed through the course of the experiment. At the end of the experiment, five out of 11 participants granted us full access to the recordings of the 30 days (including GPS location, timelapses and comprehensive lifelogs). They refused to review the dataset to remove potentially sensitive information before handing it despite the researchers urging them to do it.

No long term storage of lifelogs Unlike our expectations, only half of the participants were interested in a copy of their dataset. Several of them commented that they already know how the camera takes the pictures and seeing them at the lab was enough. On the other hand, the photos require massive storage that they are not willing to provide unless there is a clear use for the photos. For the reader to understand their rationale, we provide a rough estimate for the storage consumption of lifelogs. A 500-Gegabyte laptop can only store 249 days of lifelogs if used only for photos. An external drive of the same capacity costs around 35 €. However, it is subject to corruption and data loss on the longer span of time. Synchronizing the photos to a cloud service generates ca. 2 Gegabyte of network traffic daily. Thus, the participants did not think the immediate benefit justifies the costs[19].

[19] Note that our participants are mostly students, and are thus conservative with their financial resources

Attitudes towards Presenting Lifelogs

In this section, we discuss the users' attitudes towards adopting lifelogging. We first discuss their inclination to use lifelogging is special moments only rather than generically. Afterwards, we discuss a phenomenon where participants are not able to recognize the events and memories represented by a photo.

Use cases: Log in special moments Towards the end of the experiment, participants were mostly skeptical of the value in continuously doing lifelogging even if it were all automatic and became a part of their daily routine. Participants seem to favour domain case-based lifelogging to generic lifelogging. The effort required to alter one's behavior to optimize capturing quality along with the financial resources required to acquire the hardware and provide storage are not matched with real needs to have the technology. For example, **P4** said *"It is just for hobby and nothing particular *for now*"*. However, they would be interested to do it for special events like holidays or sports. For example, **P8** explained *"Doing it for another month, and having always the *same photos* are boring. But if I went to another place, for example for a holiday it would be interesting"*. Similarly, **P3** highlights *"I don't find the benefits for me *yet*, maybe for sports"*. However, some participants were positive about the experience. For example, **P11** offers an alternative vision, *"By lifelogging, you see a younger version of you .. It is like recalling your great past and trying to match that in your present as well"*.

Inability to recognize one's photos and corresponding events Participants were not always able to recognize the content of their photos. For example, **P5** explained "Some events just happen for the day when they usually don't happen. I looked at them and I didn't recognize them". We attribute this to three reasons. The first is low quality pictures from noise such as blurriness. For example, **P5** explains *"I actually didn't know the quality of the camera but I knew it wouldn't be as good as the *proper cameras*. But, it was up to my expectation to the extent that very few photos were blurred. Like most of the time, I could see what was going on in the photos"*. The second reason is the discrepancy between how we perceive the world and the angle captured by the camera. For example, **P3** challenged the value of the captured photos saying *"the pictures were not really showing what I wanted to see which is what my eyes see .. somehow I was looking and I knew I was going to see pictures that do not really show what I saw"*. The third is the lack of contextual information to comprehend the photo. For example, **P10** commented *"Sometimes the pictures are so vague, so I*

am wondering where am I?". We also observed a case when a participant started the experiment with an orientation in our office one evening, while the camera had automatic photos of the office from that morning. In the weekly review, the participant narrated events related to the morning lifelogs and failed to report that the review had alien logs.

6.1.5 Lessons Learnt and Takeaways

Reflecting on our experience in designing the full-stack system for the experiment enabled us to identify most of the parameters in the *MemAlt* pipeline. Through this experiment, we learnt that generic memory augmentation through daily reviews is challenging. Despite knowing from the psychology literature that reviewing content helps us remember it better (see Section 2.3), the intrinsic memory enhancements were not substantial in real scenarios from basic reviews despite the high relevance of the presented content. Thus, further research is required to identify the required number of repetitions of the reviews to cause quantifiable memory enhancements while keeping the system interesting and usable. Such systems are currently better suited for the objective of reminiscence and potentially reflection. This was also reflected in our participants proposing to use lifelogging on special occasions rather than generically. Similarly, they were interested in the "Life-Dome" prototype and voluntarily used it for reflection on their habits and patterns although that was not part of the initial experiment. They frequently used it to understand how they spent their time within the week and reach new insights about their new activities. Thus, we recommend following that line of research in designing comprehensive parallel reviewing techniques for the full datasets of lifelogs.

We postulate also that lifelogs are harder in imparting information and implicitly augmenting the memory because participants are not familiar with the photo angles and perspectives. This was reflected in several of our participants not being able to recognize the context of their lifelogs or if the photos belonged to them or not. This phenomenon coupled with their trust in the correctness of the digital system and that it would never show data that was not theirs create an unprecedented effect. Such effect opens a research opportunity for investigating the potential of memory alteration (implantation or attenuation) using lifelogs. An example would be including photos that do not belong to the person but with coherent aesthetics to their lifelog to change their perspective about a certain event. The techniques could either be used in positive contexts, to help psychiatric patients for example, or in malicious contexts.

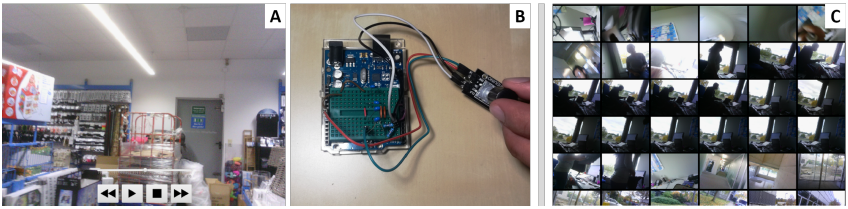

Figure 6.8: An overview on the design of the LifeRewinder project. (A) shows a timelapse sequential visualization for comprehensive lifelogs with controllable speed using the knob in Figure B. (B) shows the architecture of the knob: a breadboard fixed on Arduino UNO, with RC low-pass filter circuit, and SE055 knob-mounted RE module. (C) shows a parallel static visualization for comprehensive lifelogs as a grid similar to what we used in RDT project.

6.2 Lifelog Speed Reviewing by Tangibles

In this section, we introduce the **LifeRewinder** project. As we have seen through the **RDT** project, parallel reviewing is better suited for larger datasets for an overview, as sequential reviewing becomes tedious. However, sequential reviewing allows the user to better focus on details. After the participants' enthusiasm about reviewing their comprehensive lifelogs using "Life-Dome" in the **RDT** project, we wanted to see if we could merge the benefits of both methods and enhance the interaction of sequential reviewing but for larger datasets. Comprehensive lifelogs refer to the complete dataset of pictorial lifelogs without removal of instances. We focus on visualizing comprehensive datasets because of their potential superiority in jogging recall as more cues trigger more parts of the episodic memory [105]. However, prior research showed that timelapses with regular speeds are cumbersome for reviewing comprehensive datasets as users transition between skimming and detailed inspection of details (e.g. [158]). To achieve our goal, we leverage *speed-altering interactions* for *comprehensive visualizations* to enhance engagement and amplify human cognition.

We built a prototype that uses knobs to leverage sequential speed reviewing of pictorial lifelog timelapses (see Figure 6.8). Participants use the knob to control the speed factor of the time-lapse in real time. We chose a tangible controller because of the environmental accessibility and the passive haptic feedback that enhances the interaction. For example, recent work investigated the usage of tangibles for capture control within the lifelogging context to support privacy (e.g. [33]). We specifically used a knob because prior work extensively used them to support input fine adjustments (e.g. [148]). Additionally, knobs are a commonly

used controller in niche applications such as DJ mixers and video editing stations to manipulate media, especially presentation speed. We evaluated our prototype in a focus group (N=6) to understand potential use cases for it. Our work in this project complements our efforts in the past project **RDT** to design and build an external memory prosthetic for augmenting the human memory.

6.2.1 Prototype Design

Our system is comprised of a proprietary wearable camera, a laptop with a timelapse player software, and a knob. We built the software and the knob (see Figure 6.8). The lifelogs are also obtained from a Narrative Clip wearable camera. The player supports seeking, fast forwarding, playing and stopping the timelapse. The knob is used to adjust the playback rate of the timelapse until it is further changed. We used a ticking incremental rotary encoder as a knob. The speed change factor for each tick was 2X, where clockwise rotation increases speed and anti-clock wise reduces it. The photos are loaded and displayed from a round-robin buffer of images that refills displayed photos with new ones in the background. This approach is favorable to encoding the data as a video to simplify controlling the speed and seeking to capture moments.

Knob Implementation To minimize debouncing from changing the ticks, we used a low pass filter for the noise and added a programmatic delay of 5 ms to fetch the output channels. The sampling frequency of the output is 200Hz to account for aliasing, assuming that a user cannot exceed a frequency of 100 shaft revolutions per second. The Arduino's code checks indefinitely for state changes on PIN A. The shaft is turned when a change from HIGH state (no rotation) to LOW state (rotation) is detected. Once rotation is detected, we define the direction via PIN B. If it has already changed its state, then this is an anti-clockwise rotation and vice versa. The rotation direction is received on the JavaFX visualization application as an ASCII character. Further implementation details can be obtained from [236].

6.2.2 Methodology

The aim of our preliminary evaluation was to: (1) identify relevant use cases for the prototype and (2) to understand the users' perceptions of parallel and sequential reviewing of comprehensive lifelogs viewed on accessible devices such as laptops. We compared them based in two scenarios: increasing the sense

of productivity and getting an overview on daily activities. The two scenarios were identified from the qualitative results of the previous project **RDT** when participants used the "Life-Dome" prototype.

Research Method: Focus Group

We invited participants to a lab session that was divided into two parts:

Individual session We compared two visualizations: (1) our prototype visualization that is a sequential timelapse and (2) a static grid view parallel visualization. We chose the grid visualization to simulate standard methods for viewing lifelogs on file management systems and proprietary software (e.g. narrative clip browser). Additionally it is commonly used as a baseline in prior research (e.g. [158]). We asked each participant about their favoured visualization to (1) enhance their sense of productivity and (2) review their daily activities. They selected one visualization per scenario. We provided mouse and keyboard controllers as well our prototype. Participants were free to use them or the knob. The knob worked only in the timelapse visualization.

Group session We invited our participants to a brainstorming session about use cases for our prototype. We used the 6-3-5 brain writing technique to encourage creativity and eliminate peer pressure (see Section 5.1 for details). Afterwards, the participants were asked to discuss and group the ideas.

Procedures

We invited the participants to a lab session where we introduced lifelogging technologies. Afterwards, the participants individually tested each visualization freely on a real lifelogging dataset provided by us of one day (has 1000 photos). The testing order of the visualizations was balanced. Both visualizations were displayed on the same laptop. Next, each participant was asked about their visualization preference for enhancing their sense of productivity and reviewing their daily activities. Lastly, we invited all participants back to the room for a brainstorming session to collect use cases for our prototype.

Participants and Recruitment

We recruited six university students (all males) through word of mouth. The mean age of the participants was 20 years old. All participants were Egyptian. Participation was voluntary and participants were compensated with a candy bar. The lab session lasted for an hour in total.

Analysis Methods

We counted the number of participants who preferred each visualization for each use case. We acknowledge the small sample size. Thus, we encourage the reader to perceive the results as exploratory research opening further research opportunities.

The lab session moderator also took notes on the interaction techniques of the participants and their comments during the lab session. Afterwards, the data collected through the 6-3-5 brain writing technique was analyzed by one researcher using values coding then thematically grouped after eliminating the repetitions.The emerging themes were also compared to the themes grouped by the participants and regrouped again. Since our objective is to inspire future research, we report on themes that occurred at least once.

6.2.3 Results

Perception of prototype Both visualizations were equally preferred for promoting a sense of productivity and getting an overview on daily activities. Although we provided keyboard controls for all interactions, all participants found the knob easier to use than the keyboard and mouse controls. We use the grid visualization as a proxy for parallel reviewing while our speed-controlled timelapse is a proxy for sequential reviewing. Participants thought sequential reviewing is useful for search and a quick overview, while parallel reviewing is useful for inspecting details.

Use cases Conforming with prior work, participants proposed using **LifeRewinder** for reflection to enhance time management and track behavioral change, leading particularly to body changes. They also proposed using it to review regular events with temporal dependency in the content such as lectures and work meetings. Moreover, they proposed three use cases which we find particularly promising:

1. **Learning and skill-transfer** Participants wanted to review lecture notes, recorded in-lab experiments and step-by-step tutorials. Some also wanted to review others' experiences to learn or enhance a skill such as cooking.

2. **Searching for lost items** Participants suggested finding lost day-to-day gadgets using "quick" videos.

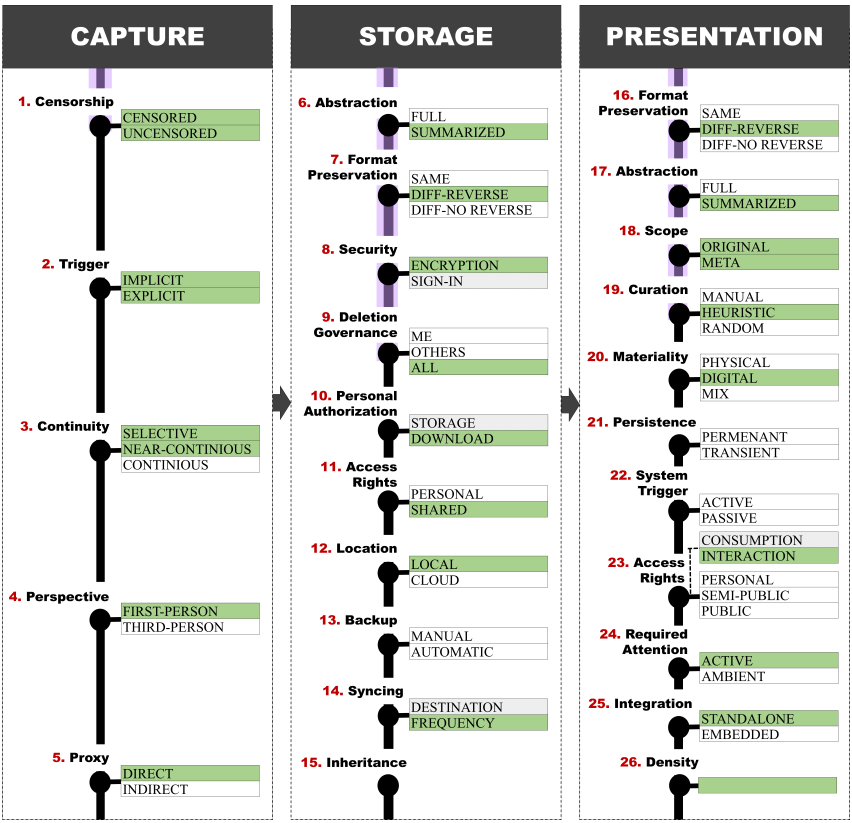

Figure 6.9: Summary of the framework parameters we learnt about through RDT and LifeRewinder project(s). The covered parameters are shaded in Green.

3. **Reflection on social rapport and interactions** Participants wanted to analyze the attitude of their social circle towards them. They argued that the passive photos would capture genuine reactions as people become indifferent to the camera.

6.2.4 Lessons Learnt and Takeaways

In this work, we focus on creating an intuitive interaction with time-lapse speeds using tangibles, i.e. a knob. The knob is used to adjust the playback rate of

the time-lapse until it is further changed. We envision that providing users with intuitive control over speed can minimize the cognitive load associated with sequential reviewing of complete lifelogs. Additionally, it can create an engaging experience of exploring the lifelogs. One could extend this work by comparing our prototype to a parallel comprehensive visualization in specific use cases such as reflection, search, enhancing sense of achievement and detecting social attitudes of bystanders.

6.3 Framework Insights

In this section, we map the project findings to the corresponding framework parameters. It shows an example for using *MemAlt* pipeline as a reflection tool to aggregate findings about systems. Figure 6.9 provides an overview on the parameters we learnt about via the project. Table 6.2 summarizes the lessons learnt about each parameter.

Table 6.2: Framework findings inspired by RDT and LifeRewinder project(s).

Parameter	Lessons Learnt
1. Censorship CENSORED UNCENSORED	**1.** (**RDT**) (`CENSORED`) Co-participants should be further considered in providing governance over capture. There were power conflicts between participants and co-participants when the latter were not comfortable about capturing common events. **2.** (**RDT**) (`UNCENSORED`) Participants tend to forget about the camera even when it captures sensitive situations such as toilet visits. **3.** (**LifeRewinder**) (`UNCENSORED`) Participants wanted to analyze the attitude of their social circle towards them as the passive photos capture genuine reactions of people.

Parameter	Lessons Learnt
2. Trigger IMPLICIT EXPLICIT	**4.** (**RDT**) (`IMPLICIT`) Co-participants often do not recognize that there is a camera automatically capturing them. **5.** (**RDT**) (`IMPLICIT`) The implicit nature of the capturing led co-participants to treating the camera as an active entity (e.g. saying hi to it for selfies) **6.** (**RDT**) (`EXPLICIT`) Co-participants tried to mimic explicit capturing through gesturing at the camera. However, this feature was not enabled in our experiment. Nevertheless, we think it would be interesting to further explore its implications on social interaction. Participants were first welcoming of the interactions of the co-participants then seemed to be annoyed as time passed during the experiment.
3. Continuity SELECTIVE NEAR-CONTINIOUS CONTINIOUS	**7.** (**RDT**) (`SELECTIVE`) Participants proposed logging in special events only such as holidays or sports. **8.** (**RDT**) (`NEAR-CONTINUOUS`) Cameras are unable to warn users when the photos are occluded by clothes or hair. Thus, users needed to restrict their wardrobe choices and hair style, which affected their experience negatively. **9.** (**RDT**) (`NEAR-CONTINUOUS`) As the camera is always on, a lot of the photos are blurry due to movement.
4. Perspective FIRST-PERSON THIRD-PERSON	**10.** (**RDT**) (`FIRST-PERSON`) Quality of captured photos is highly affected by the user's physique. Participants with shorter heights and larger busts are more prone to capturing occluded photos.
5. Proxy DIRECT INDIRECT	**11.** (**RDT**) (`DIRECT`) Participants cannot easily imagine the camera field of view. This creates disappointment as the captured photos do not match what "they see". Additionally, it prompts privacy breaches as they accidentally capture sensitive content.

Parameter	Lessons Learnt
6. Abstraction FULL SUMMARIZED	**12.** (**RDT**) (`SUMMARIZED`) The segmentation and selection of a representative photo per event is a time consuming and computationally expensive task. It took around four hours to process and generate the videos for a single day of photos on an core-i5 computer solely dedicated to the task.
7. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**13.** (**LifeRewinder**) (`DIFFERENT-REVERSE`) Transforming the photos into a video is technically tricky to implement varying speeds over time later as the developer will have to encode several versions of the video with varying speeds.
8. Security ENCRYPTION SIGN-IN	**14.** (**RDT**) (`ENCRYPTION`) The encryption and decryption process of the photos is a time consuming task. The decryption of one week's worth of data takes around 15 minutes on a core i5 computer.
9. Deletion Governance ME OTHERS ALL	**15.** (**RDT**) (`ALL`) Participants did not seem to care to post-delete photos in sensitive situations such as capturing passwords or being in the toilet.
10. Personal Authorization STORAGE DOWNLOAD	**16.** (**RDT**) (`DOWNLOAD`) Almost half of our participants were not interested in retaining their dataset after the experiment because of the large space required. **17.** (**RDT**) (`DOWNLOAD`) The average size of the full dataset of a participant including photos, time lapses and location data is 30 Gegabytes.

Parameter	Lessons Learnt
11. Access Rights PERSONAL SHARED	**18.** (**RDT**) (`SHARED`) Participants' acceptability of sharing their datasets shifted majorly throughout the experiment. Towards the end, almost half of them gave us access to their full dataset.
12. Location LOCAL CLOUD	**19.** (**RDT**) (`LOCAL`) Local storage only accessible by participants is crucial to encourage participants in longitudinal experiments like this.
14. Syncing DESTINATION FREQUENCY	**20.** (**RDT**) (`FREQUENCY`) The daily synchronization of the camera to the local computer took on average 15 minutes.
16. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**21.** (**RDT**) (`DIFF-REVERSE`) The implementation of the photos' buffer to support real time varying speed is a computationally expensive task.
17. Abstraction FULL SUMMARIZED	**22.** (**RDT**) (`SUMMARIZED`) Participants sometimes could not recognize the timelapse photos without their context. **23.** (**RDT**) (`SUMMARIZED`) Dividing photos by days in "LifeDome" reduced the search space during the search task in a weekly dataset. **24.** (**LifeRewinder**) (`SUMMARIZED`) Participants wanted to view only a subset of the dataset. For example, they suggested finding lost day-to-day gadgets using "quick" videos.

Parameter	Lessons Learnt
18. Scope ORIGINAL META	**25.** (**RDT**) (`ORG`) Full pictorial datasets in parallel reviewing using "Life-Dome" enabled participants to reflect on time spent doing tasks. **26.** (**RDT**) (`ORG`) Full pictorial datasets in parallel reviewing using "Life-Dome" enabled participants to recognize daily activities they missed otherwise in abstract versions like summarized video reviews. **27.** (**RDT**) (`META`) The search task of a representative photo for an event using "Life-Dome" was not mentally overloading. Participants took ca. 20-25 minutes to find photos for 20 events. Participants also reported it was easy. **28.** (**LifeRewinder**) (`META`) Parallel (grid) and sequential (speedy timelapse) reviewing were equally preferred for promoting a sense of productivity. **29.** (**LifeRewinder**) (`META`) Parallel (grid) and sequential (speedy timelapse) reviewing were equally preferred for getting an overview on daily activities. **30.** (**LifeRewinder**) (`META`) Participants proposed using **LifeRewinder** (sequential reviewing) for reflection to enhance time management **31.** (**LifeRewinder**) (`META`) Participants wanted to use **LifeRewinder** for learning and skill transfer.

Parameter	Lessons Learnt
19. Curation MANUAL HEURISTIC RANDOM	**32.** (**RDT**) (`HEURISTIC`) Aesthetic metrics such as brightness and minimal blurriness do not always correspond to the most representative photo of an event for the participant. **33.** (**LifeRewinder**) (`HEURISTIC`) Participants proposed using **LifeRewinder** to track behavioral change related to body image. **34.** (**LifeRewinder**) (`HEURISTIC`) Participants proposed using **LifeRewinder** to review regular events with temporal dependency in the content such as lectures and work meetings. **35.** (**LifeRewinder**) (`HEURISTIC`) Participants wanted to review lecture notes and tutorials as well as others' curated experiences such as cooking.
20. Materiality PHYSICAL DIGITAL MIX	**36.** (**RDT**) (`DIGITAL`) We observed a novelty effect while using our prototypes, especially the "Life-Dome". Participants and co-participants were excessively interacting with the camera in the first week of the experiment. Additionally, participants were verbally commenting about how impressed and excited they were to "see their week at a glance". **37.** (**RDT**) (`DIGITAL`) Participants find it hard to grasp the expected angle of the camera even towards the end of the experiment. For example, they were still surprised what the content of their laptops showed in the weekly review photos.
23. Access Rights CONSUMPTION INTERACTION PERSONAL SEMI-PUBLIC PUBLIC	**38.** (**LifeRewinder**) (`INTERACTION`) All participants found the knob easier to use than the keyboard and mouse controls.

Parameter	Lessons Learnt
24. Required Attention ACTIVE AMBIENT	**39.** (**LifeRewinder**) (`ACTIVE`) Participants thought sequential reviewing is useful for search and a quick overview. **40.** (**LifeRewinder**) (`ACTIVE`) Participants thought parallel reviewing is useful for inspecting details.
25. Integration STANDALONE EMBEDDED	**41.** (**LifeRewinder**) (`STANDALONE`) Participants were particularly impressed by the "Life-Dome" prototype and called it an experience. They took the time to interact with it outside the experimental procedures without any encouragement or instructions from the researchers.
26. Density	**42.** (**RDT**) (`DURATION`) We showed each photo in the timelapse for 3 seconds conforming with prior work. **43.** (**RDT**) (`FREQUENCY`) Showing a timelapse summarizing a day once is not enough to intrinsically enhance recall. Further research should be done to identify the trade off factor between the number of required repetitions and an enjoyable user experience. **44.** (**RDT**) (`NUMBER OF CUES`) Each time lapse did not exceed 3 minutes, conforming with prior work (40 - 60 photos max). **45.** (**RDT**) (`NUMBER OF CUES`) In parallel holistic reviewing (Like "Life-Dome"), photos should be small to avoid overloading participants with details and to enable mental parsing of events but large enough to pick salient details. **46.** (**RDT**) (`NUMBER OF CUES`) Mapping a day to limited visual units like 2 to 3 pages simplifies mental estimate of time spent on a task.

6.4 Summary

In this chapter, we explored the use case of active memory augmentation through two projects: **RDT** (N=11) and **LifeRewinder** (N=6). Both projects form an exploration for a full-stack implementation of a memory prosthetic using lifelogs. **RDT** focuses on the *MemAlt* pipeline for capturing, storing and presenting memory cues in the form of pictorial lifelogs. It offers visualizations for sequential reviewing ("Review-Me" prototype) and parallel reviewing ("Life-Dome" prototype). On the other hand, **LifeRewinder** focuses on enhancing sequential reviewing of timelapses by introducing speed reviewing using knobs. **RDT** offers a report on a one-month old deployment with continuous lifelogging from a clip-on camera. Through it, we learnt how to conduct privacy-aware memory research tailored for concealing sensitive information (see lessons learnt about *1. Censorship* and *2. Trigger* parameters). Thus, we contribute two new research methods: (1) CMC for collecting concealed memories during examination sessions, and (2) AMV for automatically validating collected information through ubiquitous measurements. We learnt from both systems that the top proposed use cases for lifelogging at the moment are centered around reflection rather than memory augmentation (see lessons learnt about *18. Scope* and *26. Density* parameters). We recognized through the qualitative data that participants do not always recognize their lifelogs. Nevertheless, they trust that the system is always right and shows them only their data. Thus, an unrecognizable photo is attributed to natural forgetting. This phenomenon is an open research gap for investigating the impact of altered lifelogs on memory implantation and attenuation.

Chapter 7

Memory Reformation via Symbiotic Sharing

In this chapter, we discuss the **SpotlessMind** project. This is a proof-of-concept prototype for sharing brain occupancy as a proxy for a busy mind recalling memories, and includes an online survey (N=43) to identify the design parameters for such systems. The mapped findings in Section 7.6 answer the second part of **RQ3** about designing active MACS for memory reformation. We envisage utilizing our results in building new memory-sharing systems that promote empathy, cognitive awareness and convergence between individuals without disclosing the actual content of sensitive memories. The results would also contribute to building future systems that support individuals in controlled reminiscence and memory recall, particularly in training contexts such as psychiatrists helping anxiety patients control their thoughts. This would be achieved by reaching states of cognitive equilibrium during symbiotically reflecting on another's state.

Figure 7.1 summarizes the parameters we chose from the framework to design our system. The abbreviation PR denotes the respective framework parameter(s). The system provides an uncensored continuous capturing mode as the EEG cap capturing frequency is high, similar to videos of live events *(PR 1,3)*. However, we sample the lower signal frequencies to reduce the stored data. Thus, it could also be considered near-continuous. The system is implicitly triggered as it automatically captures the user's brain signals *(PR 2)*, and thereby memories

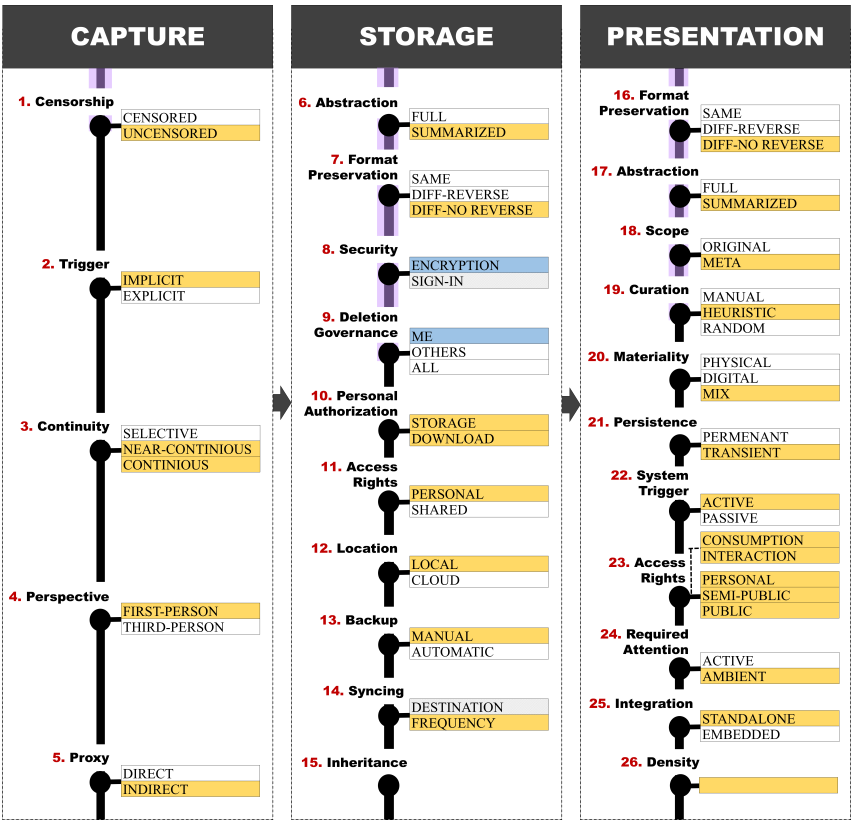

Figure 7.1: Overview on the SpotlessMind project design via the framework lens. Yellow highlights the selected parameters. Blue highlights the unspecified flexible parameters. The remaining parameters do not apply to this study.

from the first-person perspective *(PR 4)*. This affords an indirect proxy to the memories as it captures brain occupancy range rather than the specific memories the user is recalling at the moment of using the system *(PR 5)*. We store a summarized non-reversible version of the data as coefficients indicating the brain occupancy at sampled moments rather than the raw brain signals *(PR 6,7)*. We restricted the storage and download of the content to maintain the transient nature of the displayed cues *(PR 10)*. However, deletion rights and data security were left flexible in the design as a secondary element to the project's objective *(PR 8,9)*. In our proof-of-concept prototype, we stored the data locally on the researcher's laptop *(PR 11)* and manually backed it up to minimize security concerns *(PR*

13,14). The backup frequency was five minutes *(PR 12)*. Data storage inheritance was irrelevant to the scope of the project *(PR 15)*. The processed memory cues are a non-reversible meta summarized version of the stored data, i.e. the brain occupancy metric *(PR 16,17,18)*. We present the brain occupancy in an artistic symbolic way via controlled multimedia rather than showing the raw values in a direct presentation such as a graph or the coefficient itself. We also ensure that the density of the displayed cues is comfortable at all times *(PR 26)*. Thus, it provides an ambient standalone entertainment experience *(PR 24,25)*. The system is experienced digitally and physically as we add visual overlays over the physical location of the user *(PR 20)*. The transient content is heuristically curated through temporal sample and automatically displayed by the system in near-real-time *(PR 19,21,22)*. We extensively explore the access rights of users and bystanders to consume and interact with the memory cues within this project *(PR 23)*. In the remainder of this chapter, we discuss the project design in detail then reflect on how the project findings tell us more about the framework parameters. In the survey, we investigate (1) methods to present and communicate brain occupancy, (2) use-cases for sharing brain occupancy, and (3) user preferences towards sharing such states. We focus here on the first part, i.e. the presentation of the brain occupancy. However, we cover the second and the third part, i.e. the sharing attitudes and the use cases in Chapter 10, themed around the user preferences and expectations of memory altering systems.

Parts of this chapter are based on the following publication(s):

P. Elagroudy, X. Wang, E. Stemasov, T. Hirzle, S. Shishkovets, S. Mehrotra, and A. Schmidt. Spotlessmind: A design probe for eliciting attitudes towards sharing neurofeedback. In *Proceedings of the Augmented Humans International Conference, AH 2020, Kaiserslautern, Germany, 16-17 March, 2020*, pages 24:1–24:8. ACM, 2020

7.1 Introduction and Related Work

Sharing memories with others is an expression of intimacy and fosters mutual understanding and empathetic behaviour. However, understandable communication is not trivial in mentally-demanding situations when a person is thinking about several things simultaneously. Memories also can have private details that should not be disclosed. Thus, individuals can feel stressed, trapped and unable to convey

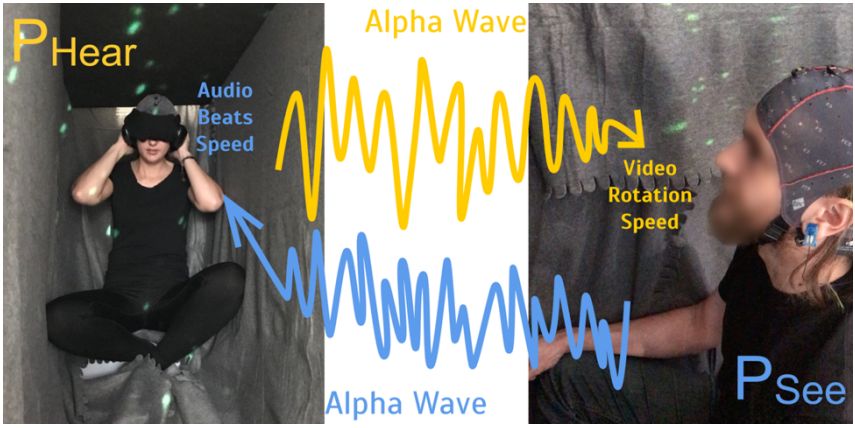

Figure 7.2: Our concept for sharing brain occupancy is called SpotlessMind. P_{hear} hears the brain occupancy of P_{see}, while he sees the brain occupancy of P_{hear}. Bystanders perceive the state of P_{see} and P_{hear}.

their temporary mental occupancy to others. Abstract implicit communication can offer a safe space for individuals struggling with self-expression. Thus, it allows others to better empathize with their state.

Brain waves have been used impactfully for artistic communication, sharing states and facilitating mutual understanding. For example, "E.E.G. KISS" visualizes the intimacy of two people while kissing via their brainwaves as "A portrait of our kiss" [155]. The advances in BCI have unbound performance artists' modalities from their body to more private and intimate ones, such as brain activities. In Lisa Park's art installations "Eunoia" and "Eunoia II", she abstracted her inner struggle, transient feelings and thoughts in front of the public as vigorous vibrations of water pools representing her passive brain waves [169, 257].

While current BCIs do not support accurate interpretation of thoughts, it is possible to detect abstract states like engagement and attention (e.g. [244, 124]). Prior work shows a correlation between changes in brain activity and recalling or retaining memories. For example, good recall performance is associated with systematic increase in alpha brain waves with a decrease in the theta signal, or a temporary decrease in the alpha and increase in the theta signals [150]. Similarly, Makada et al. showed that increasing alpha waves associated with relaxation enhances memory retention [175]. Cognitive engagement has also been detected and visualized at work [118] and in learning [24, 245, 135, 23, 177] to give user self-reflections to improve motivation and engagement. Additionally, alpha brain

waves have been used as a monitoring tool for mindfulness meditation training and behavior change activities [241].

Our work extends this body of literature by presenting an *exploratory elicitation study* to understand the design parameters for systems that share cognitive states implicitly. We achieve this goal by proposing a design concept called **Spotless-Mind** to communicate brain occupancy by controlling media in a shared artistic experience (see Figure 7.2). We define "Brain occupancy (BO)" as a cognitive state referring to how busy the mind is at an instance. We use BO as a pseudo cognitive state easily understood by the users of our research project and as a proxy indicating reminiscence. Brain occupancy has a balanced association as one could be occupied with problems or exciting topics.

We envision that systems controlling multimedia using shared cognitive states could present a modern form of "telepathic experience", i.e. a new method for sharing memories. Such systems could provide a new paradigm for sharing concealed memories to support empathy between individuals and elicit a sense of trust and openness. We also envision that two individuals can reach cognitive convergence, i.e. a loop of borrowing from the receiver's state and affecting the sender's state. For example, a meditation instructor could help a trainee achieve a calm state through reflecting on the instructor's state, while the instructor gets to reflect on the changes happening in the trainee's state in real time.

7.2 Prototype Design

We designed a shared experience enabling two users to communicate their brain occupancy in an artistic form, while including bystanders as observers of the experience. We introduce the participants' roles in this project:

- The two users simultaneously sharing their brain occupancys (sharers)
- The bystanders watching the sharers (observer)
- The sharer who sees a visual depiction of brain occupancy (P_{see})
- The sharer who hears an auditory depiction of brain occupancy (P_{hear})

Each participant can only perceive the brain occupancy of the partner through a single modality. One can only see (P_{see}) while the other can only hear (P_{hear}). During low brain occupancy (i.e. a relaxed state), the users perceive tranquil

auditory or visual depictions. The depictions become more dynamic as the occupancy increases. The changes remain in a comfortable range to emphasize the balanced association. We chose auditory and visual depictions as they are the literature standard for communicating brain waves (e.g. music depictions in [268, 95] and visual depictions in [93, 21]). We eliminated the sensory depiction of one's own state to help the sharer immerse in the partner's state to achieve the primary goal, i.e. mutual understanding and memory sharing. The installation could be set in private or (semi-)public spaces like offices and exhibitions.

7.2.1 System Setup

We focus here on describing the design setup rather than the technical detection and the mapping of the brain occupancy as we acknowledge these are simplistic in our proof-of-concept model. The setup (see Figure 7.2) is composed of a laptop, two commercial wireless BCI caps, a projector, two noise-cancelling headphones, blindfolds, and black curtains. We created a dark cave using the curtains for the sharer with a viewing window for the observers. Both sharers wear the BCI cap. P_{hear} additionally wears blindfolds and a noise-cancelling headset streaming the occupancy music of the partner. P_{see} watches the occupancy circles of the partner in silence while wearing a noise-cancelling headphone. The observers can hear the music and see the video.

7.2.2 Detection of Brain Occupancy

We mapped high-amplitude alpha waves to low brain occupancy as these are associated with calmness in meditation literature (e.g. [95, 19]). EEG signals are acquired using the g.tec wireless recording headset[20]. The headset reads a raw EEG signal from eight electrodes as separate channels with 128 Hz sampling frequency. We average the alpha signal from all the channels then average every 100 samples to account for potential noise in the signal. We map the average Alpha value to the speed of the depictions.

[20] Model: g.Nautilus: `https://bit.ly/29tODx2`

7.2.3 Depiction of Brain Occupancy

We chose *audio and visual* depictions of brain waves as they have commonly been used in prior work. For example, Wu has shown that the passive EEG signals of two different sleeping states can be converted into musical tones with distinct emotional expressions [268]. Additionally, music and the emotions felt by the listener had a notable influence in the passive brain activity [103, 94]. Similarly, researchers and artists have also developed BCI for conscious and unconscious visual expressions and creative insights. For example, "PsychicVR" relates the electrical activities of the brain to 3D contents in virtual reality, to help the user increase mindfulness and concentration [21].

The visual depiction is a video projection of universe stars [21] that rotates faster with increased brain occupancy. The occupancy's auditory depiction is ambient music with nature sounds[22] with an overlaid beat. The beat becomes faster with increased occupancy.

7.3 Methodology

We used our prototype as a project to jog the participants' imagination and collect design feedback about systems communicating cognitive states. Thus, we specifically targeted *two* research goals:

1. Concept evaluation: We also wanted a preliminary evaluation of our design concept. We deliberately decided against an in-situ evaluation, as a setup with two BCIs in a public space (e.g. an exhibition) would have presented challenges in robustness, privacy, and scalability given the current limitations of the hardware.

2. Design requirements: We wanted to understand more about (1) methods to present and communicate brain occupancy, (2) use-cases for sharing brain occupancy, and (3) user preferences towards sharing such states.

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[21] Video: `https://bit.ly/2InO9Nj`

[22] Music: Jonn Serrie - The Far River (`https://bit.ly/2U7gPtW`)

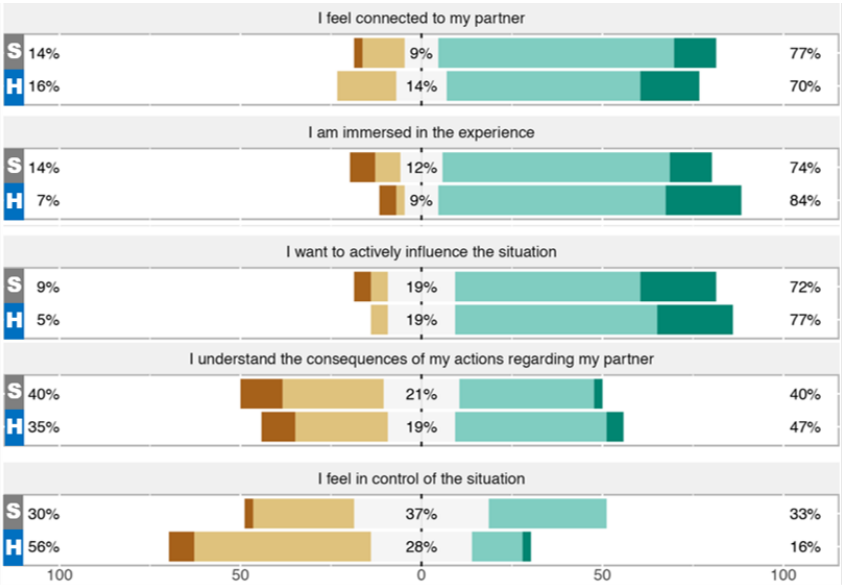


Figure 7.3: The sharers found our concept immersive and supporting connectedness. (S) denotes P_{see} while (H) denotes P_{hear}.

7.3.1 Research Method: Online Survey

We instrumented an online survey with a video explaining the concept inspired by speculative design methods. The video explained our concept of brain occupancy and the proposed system, and showed a short snippet of videography exhibiting the installation by two researchers to jog the participants' imagination. The video lasted for 2 minutes 30 seconds and was accessible throughout the survey.

The survey had three sections: (1) attitudes towards the concept, (2) concrete depictions of brain occupancy using the Aristotelian senses (vision, audition, somatosensation, olfaction, and gustation), and (3) attitudes towards sharing brain occupancy along with use-cases for the concept. All Likert items used a 5-point scale (1=strongly disagree, 5=strongly agree).

In the first section, we used Likert items to evaluate interest in the system. We requested that participants take on the roles of P_{see} then P_{hear} and asked them questions on how connected, immersed and in control they felt (see Figure 7.3 for samples). Afterwards, we changed the perspective to the observer asking the questions in Figure 7.4 to also understand their interest. Finally, we asked

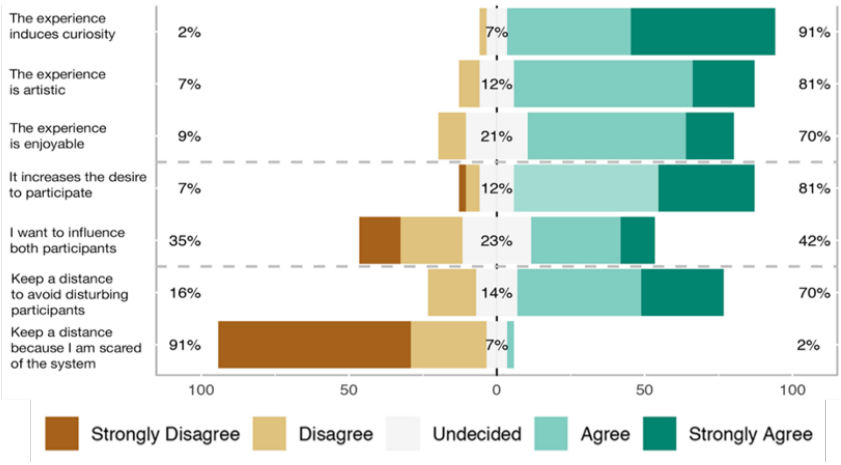


Figure 7.4: The observers were interested to try our concept and found it enjoyable

whether the observers could influence the experience or not and collected the rationale via an open-ended question.

In the second section, we similarly used Likert items to ask about modality preferences to represent the brain waves using each of the Aristotelian senses (see Figure 7.5 for sample questions). We also asked how they would map increasing brain occupancy to each sense.

In the third section, inspired by prior research (e.g.[185, 59]), we asked if the participants would share their brain occupancy or not with four groups: romantic partners, family, colleagues, and strangers. We collected the rationale and usage scenarios via an open-ended question.

7.3.2 Procedures

After collecting electronic consent from our participants, we collected their demographic data, such as age, gender, nationality, and occupation. We also asked about their previous experiences using or working with BCI devices. Afterwards, we asked the participants to watch the video before answering the questions. All questions except for open-ended ones and the demographics were obligatory. All participants were presented the survey questions in the same order.

7.3.3 Participants and Recruitment

The questionnaire was disseminated over a set of public groups on social media, various mailing lists and personal invitations. Participants were able to enter a lottery to win one of five Amazon vouchers valued at 5€ each. One hundred ninety seven participants initially attempted to complete the survey. Data from participants who did not fully complete the survey was excluded from any analysis. Thus, our analyzed sample consisted of 43 participants (1 non-binary, 17 female, 25 male) with an average age of 27 (range: 21-43). The participants' occupations covered faculty positions, different graduate stages, creative work in design, and various jobs in technological domains such as software development. Fifteen participants had tried BCIs before, while 10 had actually worked with them (i.e. developed or conducted research). On average, the participants took approximately 26 minutes to complete the survey.

7.3.4 Analysis Methods

After excluding incomplete surveys, we used descriptive statistics on Likert-item questions to evaluate the user attitudes. We conducted thematic analysis on an open-ended question. We used open-codes on the questions then regrouped the codes thematically. We reported on patterns reported at least once in the qualitative data.

7.4 Results

We reflect in this section of the concept evaluation and the first part of the design requirements, i.e. methods to present and communicate brain occupancy. Afterwards, we cover the use cases of brain occupancy and the user preferences towards sharing.

7.4.1 Concept Evaluation

The majority would like to see the system (98% agreement) and try it (79% agreement). Forty two percent found the representation of the brain occupancy in the video easy to understand, while 35% disagreed and 23% were undecided.

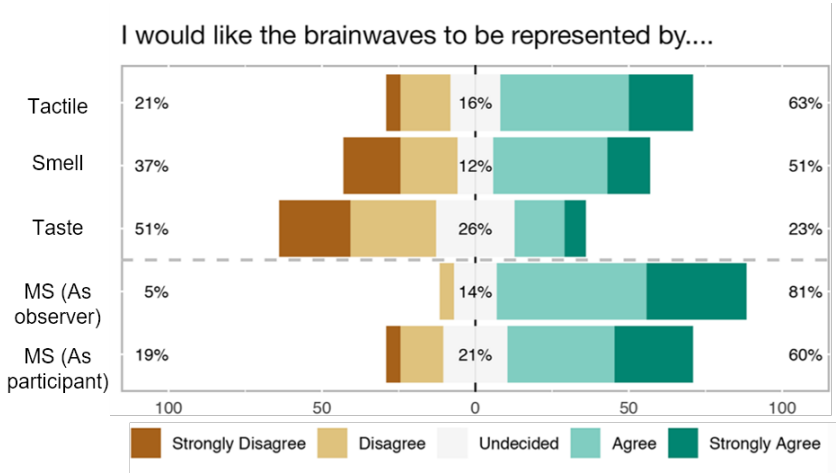


Figure 7.5: Participants, especially observers, wanted multimodal depictions and appraised additional somatosensory depictions. (MS) denotes multiple senses.

Participants' perceptions as sharers

Figure 7.3 compares the attitude from the perspective of P_{see} and P_{hear}. Both felt connected to their partner (over 70% agreement). They also found the experience immersive and wanted to actively influence it (over 70% agreement). However, they do not feel confident about the consequences of their actions. Thus, they did not feel in control of the setup, especially in the case of P_{hear} (only 16% agreement) as opposed to P_{see} (33% agreement).

Participants' perceptions as observers

Figure 7.4 summarizes the attitudes of the participants as observers. The results show that the majority find the experience artistic (81% agreement) and enjoyable (70% agreement). The majority are also curious about the installation (91%) and want to participate as sharers (81%).

Impact of the observers on the experience

The participants were undecided whether the observers should be able to influence the sharers or not, as 42% of them encouraged active participation of the observers, while 35% discouraged it and 23% are undecided. To understand such results, we conducted a thematic analysis on an open-ended question to explore the perceived

Table 7.1: Visual, audio and somatosensory depictions are recommended. All sense icons are used under the "Creative Commons" licence and were designed by Takao Umehara from the Noun Project.

Sense		Base illustration	Change depicting an increase in mind occupancy
Vision		Colors, signal waves, sea waves	Increasing: color variety, saturation, luminance, speed (pulsating visuals)
Audition		Music, music beats, heart beats, stories, nature sounds (e.g. birds) = calm mind & complex sounds (e.g. traffic) = occupied mind	Increasing: frequency, intensity, speed
Somatose-nsation		Rigidity, vibration, thermal feedback, pressure, number of stimulating objects, moistness	Harder objects, faster vibrations, higher temperature & pressure, more stimuli, unclear how to map moistness
Olfaction		Synthetic scents, sweet scents, perfumes, floral/natural = calm mind, spicy/citrus= occupied mind	Increasing intensity and number of types
Gustation		Sweet, sour/salty, personalized flavours, bitter/spicy = occupied or negative states	Increasing intensity of flavours

influence of the observers on the sharers. We open-coded the answers and two themes emerged. The first is a preference that the observers should *have no active participation in* the experience and should remain passive. They believe that the observers could choose to physically interact with the sharers if they wished to affect them. The second is that simply by their presence the observers would always *impact upon the experience*, even if they remained passive. Participants commented that the degree of familiarity and comfortability around the observers would affect the sharers. For example, **P33** comments *"If they know they are being watched; the Hawthorne effect*[23] *might come in"*

7.4.2 Sensory Depictions of Brain Occupancy

Figure 7.5 summarizes user preferences for senses used to depict brain occupancy. Participants, especially the observers, wanted to have multimodal sensory depictions of brain occupancy (81% agreement for observers and 60% for sharers). Sixty three percent of the participants wanted to add somatosensory representations of the brainwaves to the installation while 51% wanted to add olfactory

[23] Wikipedia defines it as the alteration of behaviour by the subjects of a study due to their awareness of being observed" (retrieved from `https://en.wikipedia.org/wiki/Hawthorne_effect`) (last visited on 30.4.2021)

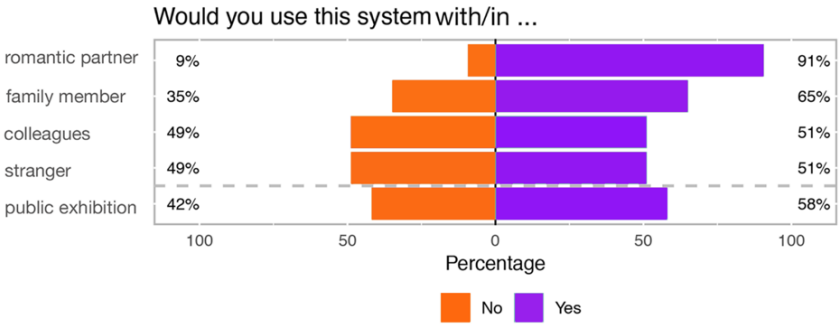


Figure 7.6: Participants are not apprehensive about sharing the BO with anyone. However, they would prefer to share it with romantic partners and family members.

representations. Nevertheless, participants disapproved of the additional gustatory representation of the brainwaves (only 23% found it appropriate).

Figure 7.1 summarizes the proposed depictions for each sense. We identify representations for the baseline denoted as *baseline illustration* and mappings for changing occupancy denoted as *changes illustration*. Participants mostly proposed abstract depictions for the baseline illustration across all the senses. For example, they proposed a heat map that gets denser with higher occupancy and a music visualizer to represent the raw changes in the brain waves using the vision. Similarly, they commonly used music and nature sounds like birds to represent a calm state and complex sounds like street traffic and horror movie tones to represent occupancy using audition. Somatosensation received the highest number of suggestions in the qualitative comments. Participants frequently combined multiple mappings such as speedy vibration with increasing number of objects generating it to communicate an exaggerated depiction of occupancy. One participant also proposed integrating the feedback mechanism to the environment such as adding vibrations to door knobs. Examples for specific depictions include mapping occupancy to a prickling feeling. On the other hand, although the majority proposed sweet depictions for olfaction and gustation, there was a division around its interpretation in relation to the brain occupancy. Participants also proposed using *olfactory* depictions to represent semantic actions rather than occupancy. For example, **P41** proposes *"Stench to keep people away or perfume to attract people"*. Interestingly, gustation was the most discredited sense in the comments in terms of likeability and feasibility.

Table 7.2: Participants want to share for fun and to answer specific questions.

Context	Use Cases	Concerns
Partner	Romantic gestures, augment sex, relax a partner, conversation starter	Misinterpretation signaling shallow relationship
Family	Gesture of trust & openness, communication mediator, understand: kids + paralyzed members	Undermine natural bond, Increases worry in negative valence states, technical complexity, comfortability
Colleagues	Communication mediator Generally not preferable	Privacy, lack of interest, lack of benefits, not appropriate for work
Strangers	Authentic interactions, scientific experiments	Privacy, generic fear, influence related to closeness w/ sharer
Exhibition	Novel experiences (interactive artistic wow)	Privacy violations because of observers, reduce immersion

7.4.3 Sharing Patterns of Brain Occupancy

In this section, we report on the user preferences for sharing mental states through the use case of sharing brain occupancy.

Figure 7.6 summarizes the participants' preferences in selecting their fellow sharers. As sharers, participants are open about disclosing their occupancy but would rather know about the others' occupancy (74% and 84% agreement respectively). Aligning with previous work [119], 91% agreed they would share their state with their romantic partners. However, despite approving, they were more reluctant to share with family members (65% agreed to share). Only 51% of the participants would have wanted to share their state with strangers or colleagues, yet 58% agreed that they would participate as sharers in an installation if it was in a public exhibition.

Figure 7.2 summarizes the proposed sharing use cases for the system with various familiarity levels with the other sharer. The majority of the participants proposed using the system for fun regardless of the sharer's relation to them. A common use case across the user groups is getting instant feedback about particular inquiries using clear questions like "know their (romantic partner's) true opinion about my favorite movie/series, although it can show high mind activity out of dislike when I think they like it" **(P14)**. We discuss below special scenarios for each group.

G1: Sharing with Romantic Partners

A recurrent use case was sharing as a romantic gesture to show intimacy, particularly on a sexual level: "I do BDSM[24], so I already share a lot of mind-states, that would be another experience" **(P6)**. Others proposed to capitalize on the existing intimacy to deliberately relax a partner using the installation, implying convergence. They also proposed using it as a conversation starter to inspire follow-up discussions: "Connecting both partners and allowing them an intimate discussion afterwards" **(P24)**. However, they did express concern about the negative implications of misunderstandings implying a shallow relationship.

G2: Sharing with Family Members

Participants proposed using the prototype to better understand their children or disabled family members. However, like G1, communication mediation to understand a member's perspective about a controversial topic was recurrent. **P33** explains *"before having a serious conversation; to prepare for the worst"*. While some considered sharing as a gesture of trust and openness, others found it undermining for family bonds as they should naturally understand each other. They were also concerned about the system's technical complexity and comfort for daily use.

G3: Sharing with Colleagues

Privacy concerns were the paramount theme because as **P13** says *"professionally what matters is what they say not what they think/feel"*. Additionally, the participants highlighted their lack of interest in their colleagues' mental state: "The sharing of the mind state with this system is too abstract for sharing actual information; so no use for productivity; but at the same time too intimate to share it with colleagues" **(P24)**. Although some participants proposed using the installation to mediate communication conflicts, others found it inappropriate and artsy.

G4: Sharing with Strangers

Privacy concerns and generic fear of sharing were the dominant theme. However, some argued that sharing heightens the experience authenticity. For example, **P37** says *"Strangers are easier to communicate with on a more intimate level; if you know you are not likely to meet this person later in your life"*. Interestingly,

[24] Bondage, Domination, Sadism and Masochism

participants link the magnitude of their influence on the experience with their closeness to the other sharer. For example, **P36** says that sharing with strangers can be more *"chaotic"*, while **P30** thinks that sharing with someone I know would have higher influence. Despite their reservation, participants were open to share within scientific experiments.

Sharing in a public exhibition

Naturally, participants were concerned about privacy infringements in an exhibition setup. **P24** explains *"Because of the observers I would decline. I do not wish for my erratic thoughts to be visible or audible to strangers; even if they cannot be deciphered directly, one can still see how active my thoughts are"*. Some participants would only share with familiar sharers in the exhibition setup. This is surprising as the observers would still be able to perceive the system output. However, they are primarily interested in novel experiences. They appraise the setup as an interactive artistic experience that resembles a performance: "Experiences made in galleries or museums tend to need a spectacle/wow-factor nowadays. This project would serve this gap quite well" **(P39)**. However, some participants believe the exhibition setup would reduce the immersion.

Forbidden sharing scenarios

Aligning with prior work [119], participants refused to share because of: privacy and lack of trust, fear of rejection and judgment, considerations to others and lack of reason to share. They particularly feared judgment in cases of: (1) concrete depictions, (2) power imbalance with the other sharer and (3) judgmental observers within their social circles. **P23** explains *"[It]depends on the representation and how it's associated with my social image to people. A bunch of lights and ambiguous sound sure but themed images that could show stuff that could be misunderstood and attributed to me not so sure"*. They also found the system inappropriate with partners like bosses and bullies as **P13** says *"They (bullies) will know better how to push my buttons"*. We also had two new reasons: (1) faking social cues during interactions such as hiding boredom in a party, (2) high cognitive load situations like exams and presentations as the prototype would be distracting.

Stake-holders	**Observer**	Perceive which sharers?	Can observer impact sharers?	Familiarity & power dynamics
	Sharer	Perceive own state?		
Location		Private (E.g. home)	Public (E.g. museum)	
Abstraction		Show brain activity?	Show meta relevant action?	
Depiction		Use single / multiple senses?	Which sense(s) to use?	
		Design base illustration	Design changes illustration	

Figure 7.7: Consolidated design parameters for creating BCI experiences supporting collaborative sharing of cognitive states.

7.5 Lessons Learnt and Takeaways

Participants perceive sharing as means to prove closeness and mediate communication. They want to share their brain occupancy with romantic partners and family members. They share to strengthen the bonds as a sign of openness and trust, and to show emotional and/or sexual intimacy. Additionally, such systems can act as a communication mediator and a conversation starter to encourage empathetic behaviors. However, concrete interpretations like assigning opinions to topics based on the system output may result in discord and hinder communication due to the limited accuracy of BCIs . Additionally, considering the power dynamics between the sharers is important to interpret sharing behaviors. For example, in contrast to prior work [119], users would not share their cognitive state with superiors to avoid deliberate manipulation.

Designers should also understand the prior relationship between the sharers and the observers to consider the impact of familiarity and comfort on accepting the experience. They should also introduce inherent constraints or explicit interaction opportunities to cue the relationship. It is worth noting that not all sharers define their relationship with the observers as “sharing” even though the observers can perceive their state.

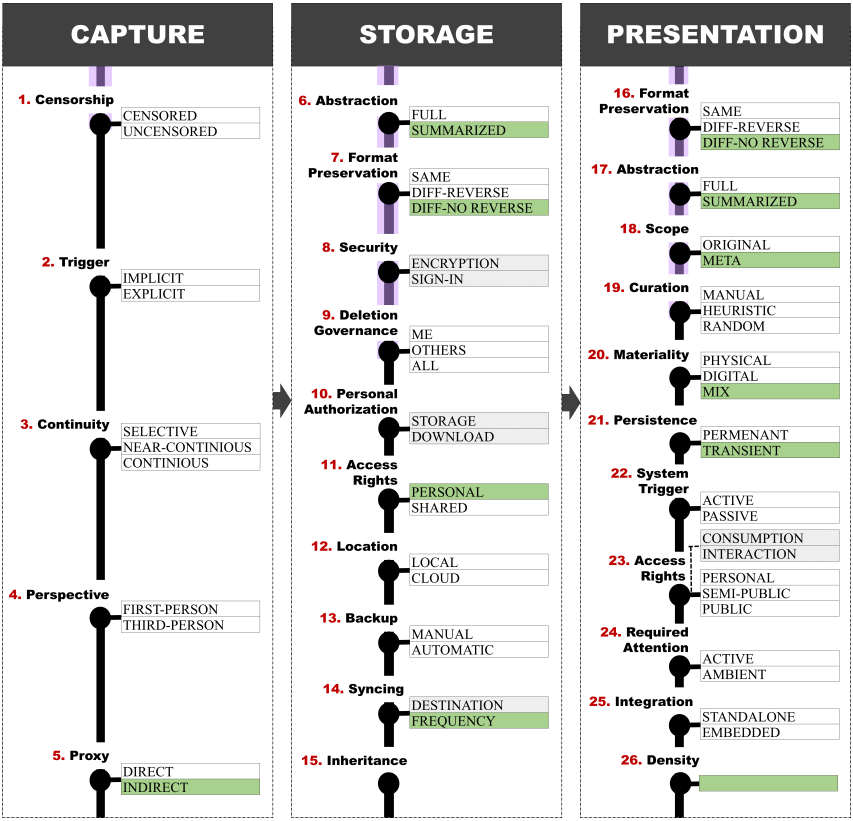


Figure 7.8: Summary of the framework parameters we learnt about through Spotless-Mind project(s). The covered parameters are shaded in Green. Most of the insights were related to the the Storage and Presentation layer.

We propose a framework to think about BCI experiences supporting cognitive communication (see Figure 7.7). It is based on the survey data and incorporates our experience of building the prototype. We focus on four design parameters:

Stakeholders We consider the sharers and the observers in this model. Designers should consider whether the sharers can perceive their own cognitive state or not. They should also decide on the presence or absence of observers after considering familiarity and power dynamics. In case observers are present, one should design the interactions between sharers and observers. Additionally, they should decide whether the observers can perceive all

sharers simultaneously or can only focus on a single sharer. Figure 7.2 summarizes common relationships between sharers and respective beneficial use cases.

Location Location affects the depiction of the information. Possible venues are private (e.g. home), semi-public (e.g. offices), and public (e.g. museums and exhibitions).

Abstraction The prototype could represent either the cognitive state (e.g. engagement percentage) or the derived meta action based on the state (e.g. do not disturb).

Depiction This refers to how the information is communicated. Designers should consider if they will enable multimodal depictions and select the target sense(s). Additionally, they should select a base illustration for representing the state (e.g. music) and another for depicting the change (e.g. speed). Figure 7.1 summarizes possible base and change illustrations based on the chosen sense. Visual, auditory, and somatosensory representations are the most viable depictions for brain occupancy. Somatosensorics are particularly versatile. Olfactory and gustatory depictions are more susceptible to causing discord. Abstract depictions are favorable and increasing speed is the most commonly proposed mapping to an occupied mind. Surreal representations provide room for interpretation reducing misunderstandings and fear of use while focusing on the empathetic experience. However, concrete representations cause privacy alerts.

7.6 Framework Insights

In this section, we map the project findings to the corresponding framework parameters. It shows an example for using *MemAlt* pipeline as a reflection tool to aggregate findings about systems. Figure 7.8 provides an overview on the parameters we learnt about via the project. Table 7.3 summarizes the lessons learnt about each parameter.

Table 7.3: Framework findings inspired by SpotlessMind project(s).

Parameter	Lessons Learnt
5. Proxy DIRECT INDIRECT	**1.** (`INDIRECT`) Participants were negatively concerned about potential discord with others from inaccurate sensing of the mental state if the receivers believe it to be accurate. We speculate that this is critical as the system senses a generic indirect cue, i.e the alpha wave, and uses it to label an abstract mental state, namely an occupied mind. Thus, concrete interpretations like assigning opinions to topics based on the system output were not welcomed as they may cause discord and hinder communication.
6. Abstraction FULL SUMMARIZED	**2.** (`SUMMARIZED`) EEGs generate high volumes of data that were not required in our case (128 Hz). We needed average values on larger time intervals so that the changes are perceivable by the audience and to account for the noise in the signal. Additionally, the original sampling rate would deplete our storage and transmission resources. Thus, we used averages of every 100 samples from the eight electrodes. However, the downside of this approach is reducing the accuracy of the state detection as the alpha signals are not emitted uniformly in all the brain regions.
7. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**3.** (`DIFFERENT-NO REVERSE`) We stored only the speed factors to avoid storage depletion, and to protect the privacy of the participants, as biological data is considered sensitive.
11. Access Rights PERSONAL SHARED	**4.** (`PERSONAL`) Only system administrators had access and control over the stored content. None of the stakeholders proposed downloadable content.

Parameter	Lessons Learnt
14. Syncing DESTINATION FREQUENCY	**5.** (FREQUENCY) Real-time data synchronization with commercial EEG caps is a challenging task. Thus, it is not recommended to use them for in-situ time-sensitive scenarios where accurate real-time feedback is required. Designers should also account for the delay while presenting the data for their use cases. We were reporting here on the general mental state. Thus, we were displaying delayed content in our proof-of-concept prototype.
16. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**6.** (DIFFERENT-NO REVERSE) The content was captured as raw brain waves, then it was processed and displayed as interactive media without hashing the reversing equation to transform the speed factor back to raw waves. The transformation is to increase the understandability of the content and create an artistic experience out of it. The function is not reversible to protect the privacy of the participants and prevent the storage of critical biological data.
17. Abstraction FULL SUMMARIZED	**7.** (SUMMARIZED) Abstract depictions are favorable for BO as they provide room for interpretation reducing misunderstandings from inaccurate sensing. **8.** (SUMMARIZED) Concrete representations such as showing a graph of the BO or clearly marking the mental state of the partner cause privacy alerts. **9.** (SUMMARIZED) Increasing speed is the commonly proposed mapping to an occupied mind. **10.** (SUMMARIZED) Olfactory and gustatory representations of BO are best implemented by manipulating the intensity of the flavor or scent, where higher intensity corresponds to a busier mind. **11.** (SUMMARIZED) Changes in BO represented via somatosensation were versatile, less intuitive and subject to opposing interpretations (For example, does an increase in moistness correspond to a busier or calmer mind state?)

Parameter	Lessons Learnt
18. Scope ORIGINAL META	**12.** (`META`) We communicated the concept of BO to non-technical users via processed abstract representations rather than showing the raw representations such as graphs for the brain signals marking the changes in the alpha waves. We speculate this allows them to focus on holistically and ambiently understanding the state via a leisure activity rather than focusing on interpreting the data. **13.** (`META`) Although the majority proposed sweet depictions for olfaction and gustation, there was a division around its interpretation in relation to the BO. **14.** (`META`) Participants particularly proposed using olfactory depictions to nudge others towards semantic meta actions depending on the BO, such as leaving the person alone rather than presenting the BO itself.
20. Materiality PHYSICAL DIGITAL MIX	**15.** (`MIX`) To represent BO, visual, auditory, and somatosensory representations are the most favorable. Olfactory depictions were also requested but there was a division in opinion about their favorability. However, gustatory depictions are the least favorable. **16.** (`MIX`) Participants wanted to have multimodal sensory depictions of BO. **17.** (`MIX`) Somatosensorics were particularly versatile and received numerous mapping suggestions for BO.
21. Persistence PERMENANT TRANSIENT	**18.** (`TRANSIENT`) The proposed content in the setup was transient to focus on the mutual sharing moment and the theatrical nature of the setup. None of the stakeholders proposed the creation of permanent downloadable content.

Parameter	Lessons Learnt
26. Density	**19.** (DURATION) We pilot tested the system to ensure that the speed factor of the visual and auditory stimuli remained within comfortable levels at the two ends of the spectrum in BO.

7.7 Summary

BCIs are showing potential as an unconventional way to foster mutual understanding, implicitly control multimedia experiences and enhance empathy through artistic and creative expressions. In this chapter, we presented a prototype named **SpotlessMind**, an interactive and collaborative installation for dual sharing of brain occupancy while involving bystanders. Our results show that the prototype evokes the interest of the public. We use our concept as a design project to understand design parameters for building systems for mutual sharing of cognitive states (see Figure 7.7). We also propose concrete multi-sensory media for depicting brain occupancy (see Figure 7.1). Our findings show that users are concerned about potential discord in case of incorrect state sensing or system interpretation. Additionally, they are concerned about leverage of observers as they learn more about their mental state (see lessons learnt about *5. Proxy* parameter). Thus, abstracting visual, auditory and somatosensory depictions is a good trade-off between knowledge and protecting privacy (see lessons learnt about *17. Abstraction* and *18. Scope* parameters). We envisage creating similar systems in the future to support individuals to reach states of cognitive equilibrium by symbiotically reflecting on another's state. We also envisage this as a novel way for sharing concealed memories between individuals. The use case could foster intimacy, and could also be used in training contexts (e.g. psychiatrists helping anxiety patients control their thoughts during attacks).

Chapter 8

Memory Augmentation To Feel Familiar

In this chapter, we discuss the **CampusBuddy** project. This is a participatory design focus group to curate and display shared memory cues on a university public display to reduce students' stress. Through sketching activities with the participants, we identify content categories that shall be displayed on a campus public display. The mapped findings in Section 8.5 answer the first part of **RQ4** about designing ambient MACS for memory augmentation. We envision utilizing our results in building memory-altering systems to provide an innate sense of familiarity and preparedness in new overwhelming situations. This is achieved via prior ambient introduction of relevant reminders and information.

Figure 8.1 summarizes the parameters we chose from the framework to design our system. The abbreviation PR denotes the respective framework parameter(s). The system provides an uncensored selective capturing model as no specific capturing conditions are predefined and users capture specific moments at their discretion *(PR 1,3)*. First and third-person captures are available depending on the content creator *(PR 4)*. For example, a student using their mobile phone to capture a photo at their graduation (1st-person) vs. the professional university photos documenting the event (3rd-person). In-situ memory cues of situations and generic reminders being captured provide direct and indirect proxy capturing modes *(PR 5)*. Capturing triggers are not applicable within this context *(PR 2)*.

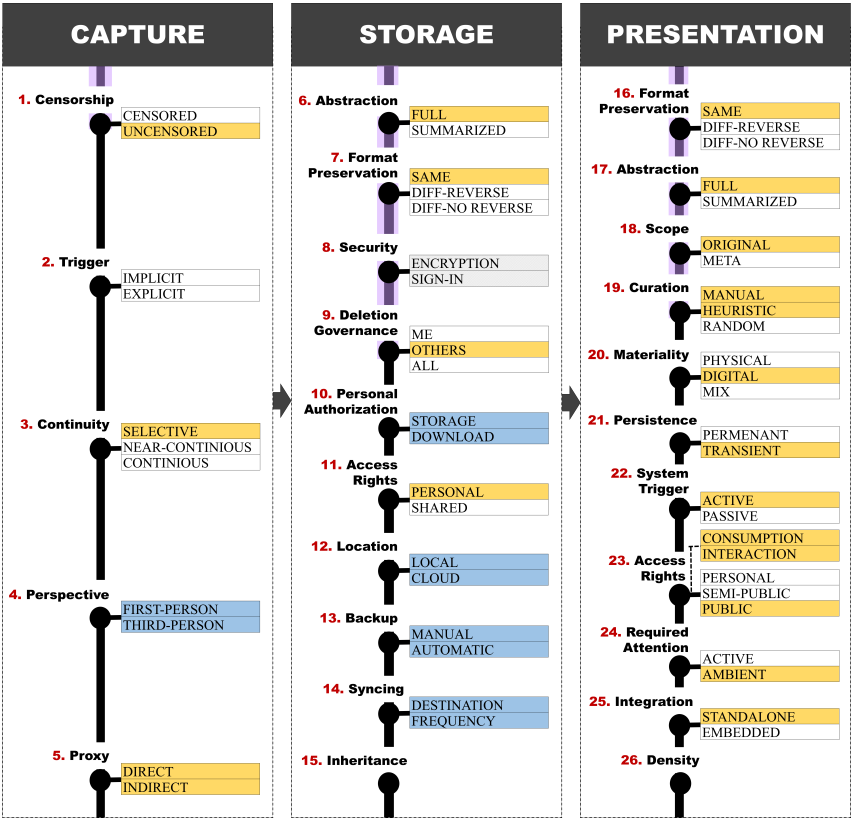


Figure 8.1: Overview on the CampusBuddy project design via the framework lens. Yellow highlights the selected parameters. Blue highlights the unspecified flexible parameters. The remaining parameters do not apply to this study.

The captured content is stored without format changes or summarization *(PR 6,7)*. The raw material viewing and the deletion are centrally controlled by the system administrator *(PR 9,11)*. Data security is not tackled within the scope of this study *(PR 8)*. However, personal authorization for download and storage, data storage and backup location, and synchronization strategies are left flexible in the design as secondary elements to this project's objective *(PR 10,12,13,14)*. Data storage inheritance is not applicable within the scope of the study as it depends on the local legalisation of the countries *(PR 15)*. The memory cues are presented digitally as is without changing the format, abstraction or scope *(PR 16,17,18)*. They are selected manually by the system administrator following

heuristics imposed by the university policies *(PR 19)*. The density of the cues in a single display is left variable for participants to decide during the focus group *(PR 26)*. The screen automatically shows public digital content to students as a standalone experience *(PR 20,22,23,25)*. Viewers interact with it ambiently with minimal fixation moments before the content disappears *(PR 21,24)*. In the remainder of this chapter, we discuss the project design in detail then reflect on how the project findings tell us more about the framework parameters.

Parts of this chapter are based on the following publication(s):

S. A. Safwat, E. Osama, P. Elagroudy, and S. Abdennadher. Campusbuddy: how can campus public displays help students feel at home? In *Proceedings of the 8th ACM International Symposium on Pervasive Displays, PerDis 2019, Palermo, Italy, June 12-14, 2019*, pages 27:1–27:2. ACM, 2019

8.1 Introduction and Related Work

Stress has adverse effects on the mental and physical health of university students. These can include learning impairment, depression, irritability, and overall decline in perceived quality of life [275]. One study with 67,308 participants surveying U.S. college students found that 75% reported suffering from stress and anxiety, 24.3% had thought about suicide and 9.3% had attempted it [170]. The study attributes the stress to heightened expectations, and pressures associated with developing a sense of self-identity and the changing surroundings while lacking guidance. We refer to those as *underlying stressors*.

Some universities have recently started to install large screens on campuses for enhancing the learning experience [184]. Prior work (e.g. [140]) investigated using campus public displays as a communication extension for the student community and for broadcasting students' preferred content. For example, Memarovic et al. [182] investigated the adequacy of communication channels such as public displays or emails to communicate various content like relevant academic material and upcoming cultural events. Also, Friday et al. conducted long-term experiments with public displays to support users in creating their own content rather than consuming preset information [97]. Prior work also used public displays to interactively collect and visualize stress metrics from university students (e.g. [193]).

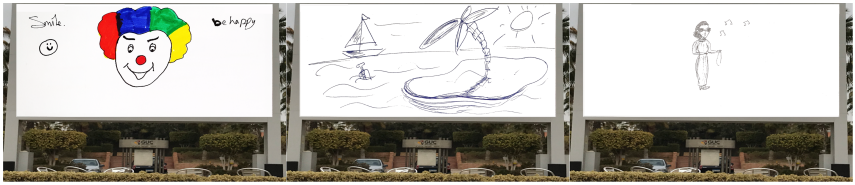


Figure 8.2: A sample of the drawings in the freshman focus group. The background shows the campus public display to help in setting the context for the participants.

Our work here extends this domain by identifying content categories for campus public displays to ease the daily life of students. We consider the displayed content as ambient memory cues implanting knowledge and memories about various segments of the university life. We conducted three focus groups (N=19) in Egypt with academics, freshmen and senior students to (1) explore content preferences and (2) understand if the preferences target the underlying stressors. We envision that well-designed content for public displays could be a digital intervention to help overcome underlying stressors in academic life and empower students to feel "at home" and in control.

8.2 Methodology

Our aim was to identify relevant content categories for public displays in an educational context to reduce stress. We particularly wanted to understand the conflict in content choices between the perspective of the students and the academics. This could shed the light on the vision difference between system administrators and content curators (academics in this case) and the consumers (the students in our study).

8.2.1 Research Method: Focus Groups

We gathered the data from three focus groups: 1) **academics** like teaching assistants and professors (N=7), 2) **freshmen** referring to first-year undergraduates (N=6) and 3) **seniors** (N=6), in this context referring to older undergraduates starting from the third semester. We ran the study at the German University in Cairo in front of the actual screens to ensure participants' prior familiarity with the displays and the context.

8.2.2 Procedure

The session started by introducing the context. Next, we gave each participant an A3 printed sheet of paper with three campus screens (see Figure 8.2) asking them to sketch content they would like to see on the screens and briefly describe it. We explicitly told the academics to design content for the students. The task lasted for 15 minutes. Afterwards, the participants presented and discussed their outcomes.

8.2.3 Participants and Recruitment

We invited 19 participants (11 females, 8 males) between 18 and 43 years (Mean= 23 years, SD=6.2). Participants' academic background varied between Engineering, Applied Arts and Design, Pharmacy and Management. The session lasted an average of 25 minutes.

8.2.4 Analysis Methods

We analyzed the drawings using open codes referring to the content category. Two researchers tagged the drawings together and a third researcher tagged them separately. Afterwards, all tags were discussed and we grouped relevant tags into the themes below using affinity analysis.

8.3 Results

Figure 8.1 summarizes the usecases categorized by the user group. We discuss below the four qualitative content types we found from the perspective of the three user groups: (1) encouraging new activities, (2) providing career inspirations, (3) enhancing the familiarity with campus services, and (4) supporting psychological rewinding. We refrained from quantitative ordinal evaluation of type importance due to the small sample size.

Table 8.1: Summary of the required content types categorized by the user groups.

		Academics	Seniors	Freshmen
1. Encouraging Trial of New Activities				
Activity type	Extra-curricular - Scientific	■		
	Extra-curricular - Recreational		■	
	Inter-curricular			■
Location (inside / outside campus)		Outside	Inside	Inside
2. Providing Career Inspiration				
Success stories		■		
Advice about study program / relevant jobs			■	■
3. Enhancing Familiarity with Campus Services				
Generic announcements (*e.g. upcoming events*)		■		
Study-related reminders (*e.g. Classes / Exams timings*)			■	■ maps
4. Supporting Psychological Rewinding				
Relaxation	Minimize screen time	■		
	Inspirational scenery / quotes	■		
Feedback collection		■		
Entertainment			■	
5. Miscellaneous Use Cases				
Billboards for exchanging services		■		
News about inside and outside the campus			■	

Encouraging trial of new activities

All three user groups desired content that encourages students to learn and try new activities. The academics focused on extracurricular but scientific content such as general knowledge games and pointers to websites explaining recent technologies. They also focused on encouraging exploration of activities outside the university campus. They believed that success stories can ignite curiosity to try an activity. However, the senior students preferred to explore extracurricular recreational activities such as workshops and competitions on campus. Similarly, the freshmen

focused on activities on campus. However, they had no clear preference towards academic or recreational activities that are extracurricular or related to their major.

Providing career inspiration

The academics promoted career inspiration by presenting success stories and career options in the university such as videos from laboratories. The seniors did not seem interested in this category as only one participant proposed displaying success stories from the university. On the other hand, the freshmen wanted concrete advice about the available study programs and their corresponding career options.

Enhancing familiarity with campus services

The academics proposed using the displays for showing announcements such as upcoming events. However, the seniors and freshmen were equally highly interested in informative content about the campus such as the timings of classes and exams. This was surprising as one would expect that this category would become redundant after getting familiar with the campus. Freshmen were particularly interested in maps to central locations in the university.

Supporting psychological rewinding

The academics wanted to promote relaxation by minimizing the screen time and showing calm scenery and inspirational quotes. They also proposed having social media channels to collect feedback from students. In contrast, the seniors chose sports and music as favourable entertainment content. The Freshmen did not seem interested in this category as we got only one suggestion about creating interactive games and one other about showing positive messages such as ”smile today”.

Table 8.2: Summary of the perception of displaying content on the public large display categorized by the user groups.

	Academics	Seniors	Freshmen
Stress Reason	Lack of inspiration + Confusion about future opportunities	Exhaustion + Being overwhelmed	Disorientation about the new surroundings
Intervention Perception	**OVERLOADING** Source of information overload	**USEFUL** Supports behavioral change (*e.g. punctuality & new activities*)	
Requested content	• Extracurricular knowledge to widen students' horizons • Relaxing content	• Entertainment • News to gain control of surroundings	Information to increase familiarity with university

Notes on other themes

The academics proposed using the displays as a billboard for exchanging services. The senior students were particularly interested to know about the latest news inside and outside the campus.

8.4 Lessons Learnt and Takeaways

University students can suffer from stress due to low motivation, academic workload, poor performance in academia [18], and lack of time management [186]. Figure 8.2 summarizes the findings about each user group's rationale for the chosen content. We hypothesize that freshmen stress because they lack basic knowledge about their surroundings, and therefore our freshman subjects chose content to increase their familiarity with university life. By contrast, seniors' choices are possibly motivated by exhaustion, which could explain why our participants focused on entertaining content and news to gain a sense of control over their environment. However, the academics in our project seemed to propose stress interventions to combat students' lack of inspiration and confusion about future opportunities. Thus, their proposals focused on extracurricular knowledge to widen the students' horizons. Unlike our expectations, entertaining content such as movies and sports was not prevalent in any of the three user groups.

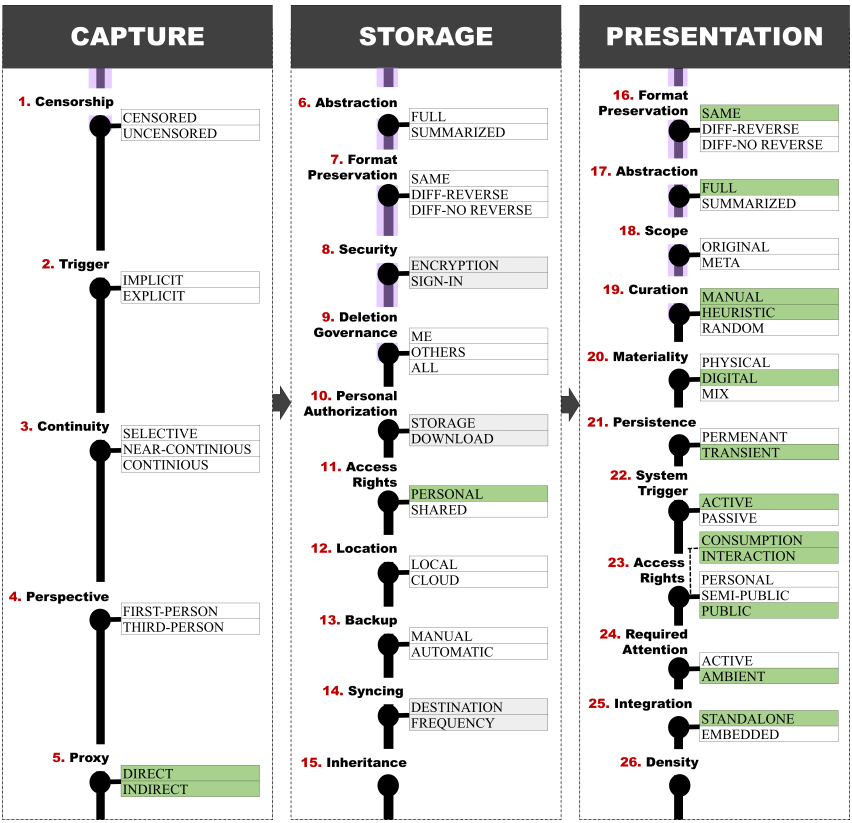


Figure 8.3: Summary of the framework parameters we learnt about through CampusBuddy project(s). The covered parameters are shaded in Green. Most of the insights were related to the the Presentation layer.

One could also argue that students perceive the displays as a useful intervention that can support their behavioral change endeavors such as being punctual and open to activities. Thus, they wanted announcements and reminders. However, the academics thought that such displays could overload students with too much information, therefore they focused on inspirational and relaxing content and even proposed turning it off for some time during the day.

8.5 Framework Insights

In this section, we map the project findings to the corresponding framework parameters. It shows an example for using *MemAlt* pipeline as a reflection tool to aggregate findings about systems. Figure 8.3 provides an overview on the parameters we learnt about via the project. Table 8.3 summarizes the lessons learnt about each parameter.

Table 8.3: Framework findings inspired by CampusBuddy project(s).

Parameter	Lessons Learnt
5. Proxy DIRECT INDIRECT	**1.** (`DIRECT/INDIRECT`) Regarding career inspiration, the students preferred direct proxies such as showing advice about study programs and relevant jobs. However, academics preferred indirect generic proxies such as showing success stories. **2.** (`DIRECT`) Regarding encouraging the trial of new activities, both the students and academics preferred direct proxies about the activity regardless of its type. **3.** (`DIRECT`) Regarding enhancing familiarity with campus services, both academics and students preferred direct proxies such as announcements of upcoming events and study-related reminders such as class timings. **4.** (`INDIRECT`) The academics proposed indirect proxies such as beautiful scenery and quotes to induce relaxation.
11. Access Rights PERSONAL SHARED	**5.** (`PERSONAL`) Only system administrators had access and control over the stored content. None of the stakeholders proposed downloadable content.
16. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**6.** (`SAME`) The content was displayed in the same format it was captured and created in. The most commonly proposed formats were text and photos followed by videos.

Parameter	Lessons Learnt
17. Abstraction FULL SUMMARIZED	**7.** (FULL) The proposed content was mostly static and we did not receive suggestions for interactive content on the displays. Thus, the stakeholders used it like a billboard rather than as an interactive device although the researchers did not impose such constraint.
19. Curation MANUAL HEURISTIC RANDOM	**8.** (HEURISTIC) The academics recommended heuristically curating content promoting extracurricular activities to widen the students' horizons or relaxing content. **9.** (HEURISTIC) The senior students preferred heuristically curating content focused around entertainment and news to gain control of the surroundings. **10.** (HEURISTIC) The freshman students preferred heuristically curating content centered around campus information to increase familiarity with the university. **11.** (MANUAL) In this project, we did not explore algorithms for heuristic curation or sources for capturing the content. The assumption is the final selection of the content is by a system administrator manually. However, one could also imagine automatic curation using preset heuristics.
20. Materiality PHYSICAL DIGITAL MIX	**12.** (DIGTAL) All the content was displayed only digitally. There were no suggestions for creating mixed experiences. However, we should carefully postulate about that as it might be an inherent limitation to the study design asking participants to design "on-the-screen" experience.
21. Persistence PERMENANT TRANSIENT	**13.** (TRANSIENT) The proposed content by nature was transient as it was controlled by the system administrators. Most of the proposed content was contextual such as class reminders. None of the stakeholders proposed the creation of permanent downloadable content.

Parameter	Lessons Learnt
22. System Trigger ACTIVE PASSIVE	**14.** (`ACTIVE`) The participants proposed automatically-displayed content without any interference from the viewers. They also proposed contextual content such as timely reminders before classes.
23. Access Rights CONSUMPTION INTERACTION PERSONAL SEMI-PUBLIC PUBLIC	**15.** (`INTERACTION`) The participants did not propose any interactive content or request specific interactions with the screen. We postulate that this confirms the ambient nature of the display for them. **16.** (`CONSUMPTION/PUBLIC`) Neither the academics nor the students proposed sharing personal content such as tweets about their university experience on the screens even after reviewing it. Instead, all groups proposed generic informative content.
24. Required Attention ACTIVE AMBIENT	**17.** (`AMBIENT`) The academics perceived campus public displays as a distraction and overloading source of information. However, the students found it useful for supporting behavioral change.
25. Integration STANDALONE EMBEDDED	**18.** (`STANDALONE`) All the proposed content by our stakeholders was focused around a single theme at a time. We did not receive proposals for mixed experiences.

8.6 Summary

Recent studies have shown that over 70% of university students report suffering from stress and anxiety [170]. Common stressors are heightened expectations and changing surroundings. Campus public displays are becoming a common commodity in universities to support communication, advertising and learning. In this work, we aim to use public displays in helping students overcome stress

through heuristically curated content. The content is perceived as a form of shared collective memory. To this end, we conducted a project with three focus groups (N=19), using sketching activities to understand the needs of three user groups: academics, freshmen and senior students. Four common content categories emerged: advertising new activities, providing career inspiration, enhancing familiarity with existing campus services, and supporting psychological rewinding. Our results indicate that students think the displays are a useful intervention, unlike academics who find them stressful. We postulate that this caused a difference in the preferred directness of the presented cues between academics and students (see lessons learnt about *5. Proxy* and *19. Curation* parameters). One could extend this work by exploring open design opportunities such as designing content that augments human memory by creating a "déjá vu" effect supporting a sense of familiarity. Our work also provides a step in the direction of ambiently imparting and transferring knowledge to masses.

Chapter 9

Memory Reformation via Lifelogging

In this chapter, we discuss the **PPMCloak** project. This is a lab study (N=12) to explore the impact of altering lifelogging photos to protect the privacy of the users while enhancing the ability to remember information from past events. We specifically look at three conditions to understand their impact on altering recalled memories: (1) blurring individuals in photos, (2) deleting a subset of the captured photos and (3) the captured unaltered full dataset (baseline). The mapped findings in Section 8.5 answer the second part of **RQ4** about designing ambient MACS for memory reformation. We hypothesize that the visual alterations in the lifelogs could be used for deliberate memory attenuation and/or implantation. We build upon our observations from the **RDT** that participants do not always recognize content in their lifelogs which offers a research opportunity for using alter lifelogs to alter memories. We envision utilizing our work in: (1) nudging system designers to consider the impact of their presentation decisions on ambient memory alterations, (2) using our study design to evaluate and compare the impact of other presentation methods on accidental memory degradation, and (3) opening new research opportunities for positive targeted memory alterations to overcome trauma, for example.

Figure 9.1 summarizes the parameters we chose from the framework to design our system. The abbreviation PR denotes the respective framework parameter(s). The

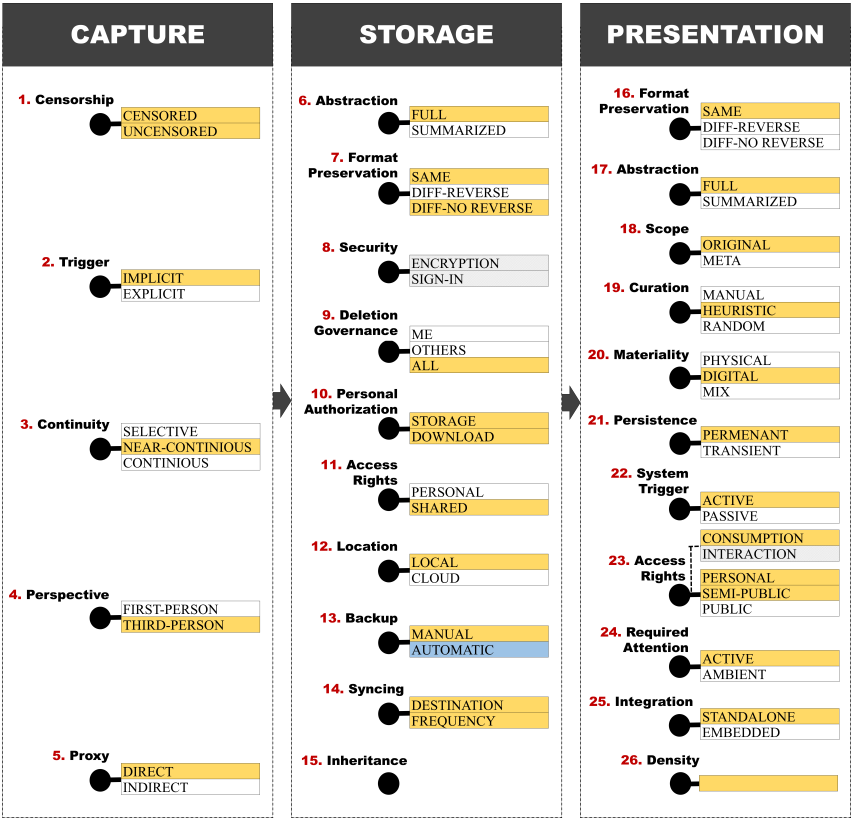


Figure 9.1: Overview on the PPMCloak project design via the framework lens. Yellow highlights the selected parameters. Blue highlights the unspecified flexible parameters. The remaining parameters do not apply to this study.

system provides censored and uncensored near-continuous automatic capture of environmental lifelogs *(PR 1,2,3)*. Using the Wizard-of-Oz technique, we mimic a system that does not capture photos when certain individuals show in them, and another that blurs individuals completely, comparing both cases to uncensored capturing of photos. The environmental lifelogs are collected centrally through wall mounted cameras providing third-person view of the captured photos for all participants showing their activities directly *(PR 4,5)*. Security was not explored in this project *(PR 8)*. Besides the intended censorship in the deletion condition during the capturing phase, all collected cues are stored locally on the researcher's laptop mimicking a system administrator role *(PR 6,12)*. Some are

stored without changes (baseline condition) and others are stored after blurring individuals, i.e. a non-reversible different format *(PR 7)*. Deleted photos are removed for everyone including the persons who were in the photos *(PR 9)*. Subsets of the environmental lifelogs are accessible to all participants based on their experimental condition *(PR 11)*. Participants are not allowed to contribute further photos to maintain the integrity of central lifelogs or to download the photos, to ensure the required information decay before testing their memory performance *(PR 10)*. As we are using Wizard-of-Oz to simulate the controlled capture, we are backing up and processing the data manually on the researcher's local computer at the end of the lab session *(PR 13,14)*. However, one could easily imagine automating the process in a deployed system. Photos were presented with the same alterations already done in the storage phase (deletion and blurring) with no new changes *(PR 16,17,18)*. Some participants had the full dataset of collected cues, while others only saw a subset after blurring individuals or deleting photos showing some individuals. Thus, the final presented digital cues were heuristically curated *(PR 19,20)*. Participants were allowed to view the photos as much as they needed in the recall session *(PR 21)*. Participants opened the folder containing the photos actively triggering the review process and focused on the photos to try and remember further details *(PR 22,24,25)*. Participants saw photos of themselves and others who attended the lab session mimicking semi-public access rights to the memory cues *(PR 23)*. Photos were shown individually and sequentially to allow participants to focus on the cues in a photo and they were allowed to browse the dataset at their own pace *(PR 26)*.

Parts of this chapter are based on the following publication(s):

P. Elagroudy, M. Khamis, F. Mathis, D. Irmscher, A. Bulling, and A. Schmidt. Can privacy-aware lifelogs alter our memories? In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems, CHI 2019, Glasgow, Scotland, UK, May 04-09, 2019*. ACM, 2019

9.1 Introduction and Related Work

There are two key challenges for developing lifelogging services: (1) how to properly address privacy concerns and (2) how to increase social acceptance of the technology [63, 151, 205, 133]. For the remainder of this chapter, we use the term "lifelogs" to denote pictorial lifelogs specifically. Lifelogs expose the

Figure 9.2: Original photo of some participants (left) vs. obfuscated version (right) where bodies are blurred (Gaussian blur, radius = 40 px). We found that privacy-protecting obfuscated lifelogs allow viewers to remember more details but with less accuracy.

activities of individuals surrounding the wearer of the camera more than they expose the lifelogger themselves. There are many documented incidents in which lifeloggers were attacked by bystanders who did not wish to be recorded. For example, Steve Mann was assaulted in a McDonalds outlet in 2012 for recording using Google Glass [240]. Therefore, researchers and practitioners investigated ways to counteract the privacy issues either by (1) deleting photos: either post-hoc or by preventing the capture of photos if privacy-sensitive situations are detected [132, 239], or by (2) obfuscating the individuals, for example by inpainting them and replacing them with avatars [167, 136]. The latter approach is particularly promising as it protects the bystanders' privacy while maintaining a better user experience for the lifelogger compared to deletion [258, 167]. However, sensitive photo elements that violate privacy often contain valuable and necessary memory cues [55].

While the impact of privacy-aware lifelogs on the lifelogger's experience was explored in prior work (e.g., see [258, 167]), the impact of privacy-aware lifelogs on the lifelogger's memory recall remains under-explored. Closing this gap is crucial because memory augmentation is a cornerstone motivation for lifelogging. However, we hypothesize that visual alterations to personal lifelogs might result in accidental memory attenuation and/or implantation (e.g. [68]). This would turn simple privacy-protection methods into ambient interventions for memory alterations.

To examine the aforementioned hypothesis and understand the interplay between privacy-aware obfuscated lifelogs and the lifelogger's recall of memories, we

report on a user study in which participants first took part in an eventful interaction session and then returned after 4-5 days to recall memories when viewing (1) 20 unaltered photos (baseline), (2) obfuscated versions of the 20 photos where persons are blurred, and (3) five out of the 20 original photos after deleting private ones. We conduct the study mimicking the use case of shared environmental lifelogs where an external entity systematically captures and distributes collective cues to all participants in an event (e.g. [57, 162]). We selected this context as one could carefully extend the findings beyond lifelogging to regular photography of events by several attendees. We tackled the hypothesis via three research questions:

1. How does the privacy-protection method impact the tendency to change recalled memories?
2. How does the privacy-protection method impact the quantity and quality of recalled memories?
3. How does the privacy-protection method impact the lifelogger's confidence in the recalled details?

Our work extends the work done by Li et al. [167] and validates the user preferences for the obfuscation methods in the context of lifelogs as opposed to generic photo sharing. Additionally, it sheds light on the trade-off between protecting the privacy in lifelogs and undermining the lifelogs' potential as a memory augmentation prosthetic. On the other hand, it opens new research opportunities for using privacy-protection methods as a strategy for altering memories (attenuation and implantation) on demand.

9.2 Methodology

The aim of our study was to investigate the impact of privacy-protection methods for lifelogs on the performance of memory recall and recognition. We experimented with two privacy-protection methods: photo deletion and obfuscation of individuals. We hypothesize that privacy-protection methods for personal lifelogs can result in memory attenuation and/or implantation. We examine the hypothesis through the three aforementioned research questions.

9.2.1 Research Method: Lab Study

The study consisted of two sessions, both of which were conducted in our lab. The first session (*Session 1*) was to create an environmental lifelog of all participants in a common controlled event to evaluate their recall of events in Session 2. Additionally, we wanted to identify the favored obfuscation method for privacy protection. The second session (*Session 2*) involved the same participants, and was to compare the impact of the privacy-protection methods on the participants' recall quality of the events from Session 1.

Using a within-subjects design would have led to biases – the information that participants gather in one condition could have influenced their responses in another. To reduce potential bias due to learning effects, we therefore opted for a between-subjects experimental design. In Session 2, we investigated one independent variable, *the privacy-protection method*, with three conditions, and measured their impact on: (1) detail recall, (2) detail recognition, (3) tendency to change already remembered details, and (4) confidence in remembered details. The verb "remember" is used as a proxy for recognition and recall within this chapter. We refer to the experimental condition as the Privacy-Protection Method (PPM). The three conditions were:

C1 (baseline) Participants viewed 20 original photos from the environmental lifelog.

C2 (obfuscation) Participants viewed an obfuscated version of (C1), where all persons were blurred (see Figure 9.2). We used *body blurring* because of positive results in prior work [32, 136, 166] and because it was the most favored in Session 1 (refer to Section 9.2.5).

C3 (deletion) Participants viewed only a subset of five original photos from (C1), mimicking deletion for privacy protection. We equally sampled them from the C1 (baseline) dataset across time.

Dataset selection criteria

In the first session, we collected over 450 photos. We used fixed temporal sampling to select the presented photos (memory cues). We sampled at five-minute intervals for the introduction and obfuscation methods. However, we reduced the interval to three minutes during the game part as this lasted for a shorter period of time (about 20 minutes). Each participant appeared at least once in their experimental lifelog dataset. We captured the photos using two opposing

cameras covering the experimental area. We alternated the sampling between both cameras to maximize the angle coverage of the session.

Evaluation of recall

Our aim was to evaluate the participants' performance in remembering, their subjective confidence about their remembered answers, and whether they perceived the photos as helpful for remembering details from Session 1. Thus, participants filled in a custom memory questionnaire where they answered 30 questions about details from Session 1. The questionnaire included personal questions (e.g., *"Every participant introduced themselves at the beginning by giving a short talk. Can you remember the hair color of Anna?"*), procedural questions (e.g., *"Please tell us the procedure of the first session as specifically as possible."*) and questions about the game (e.g., *"How many times did the players in your group have to swap their playing pieces?"*). The questions were designed by two researchers in the team then reviewed by a third researcher. Afterwards, they were labelled individually as recognition or recall questions by two researchers. Conflicts were discussed to reach full consensus about the labels.

9.2.2 Procedures

Session 1: Building the lifelog in a controlled event

Our objective in Session 1 was to create an eventful interaction between the participants to evaluate their recall of the events in Session 2. We invited twelve participants to Session 1 which lasted approximately 90 minutes. We positioned two cameras in the room to record photos from different angles to create an environmental lifelog in third-person view. Participants were informed about the recording, their consent and demographic data was collected, and lifelogging was briefly introduced.

In the first part of Session 1, we presented the 13 obfuscation methods[25] studied by Li et al. [167] to the participants (see Figure 9.3). Next, we asked them for feedback about their most favorite obfuscation method in the context of lifelogging. This was followed by a short open discussion with the participants in the form of a focus group about each technique to understand their rationale when rating them.

[25] We obtained the consent of Li et al. to use their figures

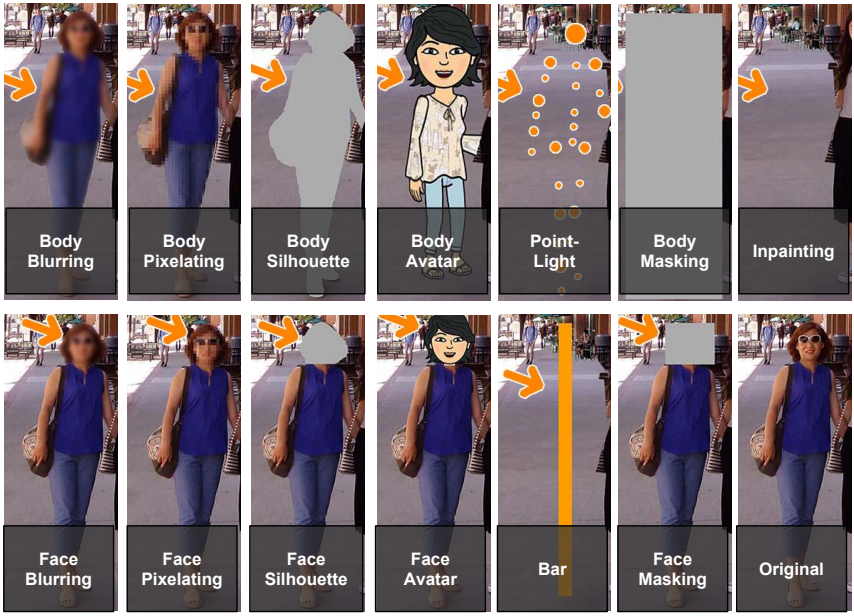


Figure 9.3: The figures above were obtained with permission from Li et al. [167]. They studied the impact of 13 obfuscation methods on privacy protection and user experience when viewing the above photos. We used the same figures in the context of lifelogging to study the impact of obfuscation on memory recall. In session 1 of our user study, participants preferred body blurring the most because of its weaker impact on the aesthetics of the lifelogs.

In the second part of Session 1, participants were randomly split into random teams of four to play a board game[26]. In the game, the players' goal is to move their playing pieces to a safe zone based on dice score. We modified the game rules by asking participants to swap seats whenever they scored certain dice values. This was done to make the recorded lifelogs more dynamic and to reduce potential bias and confusion from having most of the lifelogs seemingly static when examined in Session 2.

Session 2: Evaluating the recall

Our objective in Session 2 was to evaluate the ability of the participants to remember details about Session 1. The same twelve participants were individually

[26] An interactive German game called "Mensch ärgere Dich nicht"[129]. It translates to "Man, Do not worry".

invited to view lifelogging photos that were taken in Session 1. Each of the teams formed in Session 1 were assigned to one condition: C1 (baseline), C2 (obfuscation), or C3 (deletion) (review definitions from Section 9.2.1). Session 2 took place four to five days after Session 1 in accordance with minimum waiting times in prior work to ensure a realistic decay of information in the memory [266, 158].

We asked participants to answer the questionnaire twice: (1) before viewing the memory cues (pre-questionnaire) and (2) after viewing the memory cues, i.e., photos of the respective condition (post-questionnaire). This was done to account for prior knowledge of the answers and to identify any improvements resulting from having seen the memory cues. Participants were allowed to navigate through the photos as long as they wanted. They were also allowed to improve their answers to the pre-questionnaire in the post-questionnaire. On 5-point Likert scales, participants estimated their confidence about their answers in both questionnaires as well as the helpfulness of the photos in aiding remembering during the *post-questionnaire*. The second session lasted for approximately 1.5 hours.

9.2.3 Participants and Recruitment

We invited 12 participants (9 males 3 females) via mailing lists aged between 20 and 32 years old (mean=24.2 years, SD=3.72). Participants were compensated with an e-shop voucher worth 20€ . To motivate them to put an effort in session 2, we arranged a draw for an additional voucher, where participants who performed the best in session 2 had the highest chance of winning.

9.2.4 Analysis Methods

Selection of obfuscation method

We asked the participants to select their favorite five obfuscation methods (from the thirteen investigated by Li et al. [165]) in descending order. We counted the frequency (N) of selecting a technique in each of the top three positions (P). Afterwards we calculated a weighted score for each technique: $Score = 3 * N_{\mathrm{P=1}} + 2 * N_{\mathrm{P=2}} + 1 * N_{\mathrm{P=3}}$

Memory evaluation metrics

We used six metrics to evaluate the quality of recognition and recall. Three metrics are generated through qualitative labelling by the researchers (*Question type labels*, *Changing answers labels*, and *Correctness labels*), one metric is automatically calculated via a weighted formula of the assigned labels (*Recall Correctness Score (RCS)*), one metric is automatically computed from the self-reported scales by the participants in the questionnaire (*Confidence scale*), and lastly one metric is directly self-reported by participants in the questionnaire (*helpfulness scale*).

Question type labels Two researchers labelled the questions to indicate if the answer is directly available in the photos (recognition questions) or it is not presented in the photos (recall questions). The questionnaire had 70% recall questions and 30% recognition questions to mimic information losses during temporal gaps in pictorial lifelogs.

Changing answers labels Similar to prior work [77], an answer is considered *changed* in the *post-questionnaire* if the participants provided additional information or edited the answer they had provided in the *pre-questionnaire*. The label is independent from the correctness of the new answer. We refer to questions with changed answers as *changed or reviewed questions*.

Correctness labels We used three labels: *correct*, *semi-correct*, and *wrong* as described in Section 5.2.3. We labelled the answers in the *pre-questionnaire* and *post-questionnaire* to gauge the impact of the experimental conditions. The labels were added then discussed by two researchers to ensure internal validity.

RCS Using the assigned correctness labels, we calculated the metric as described in Section 5.2.3 for *pre-questionnaire* and *post-questionnaire* separately. Higher values denote better recall quality.

Confidence scale Participants had to indicate their confidence in their response during the *pre-questionnaire* and *post-questionnaire* on a 5-point Likert scale: "*I am confident about my answer*";1=Strongly disagree;5=Strongly agree. Afterwards, we automatically computed three custom labels based on the difference in the confidence levels between *post-questionnaire* and *pre-questionnaire*: *confidence-increased* denoting an increase in the confidence after introducing the condition, *confidence-decreased* denoting a decrease in the confidence, and *confidence-unchanged* denoting the lack of changes.

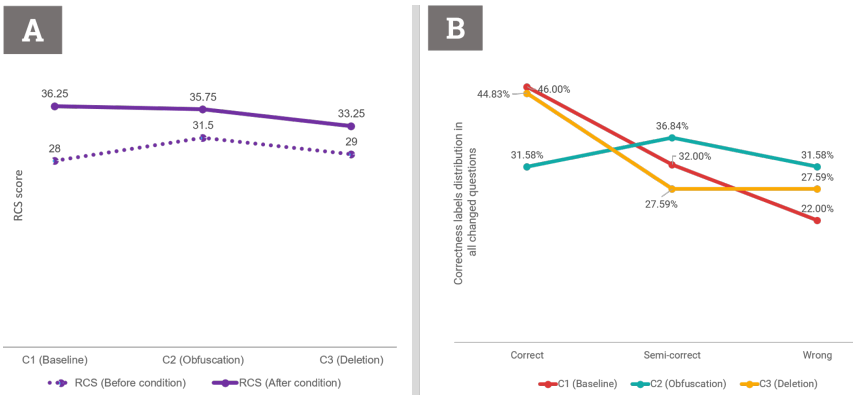


Figure 9.4: (A) summarizes the Recall Correctness Score for each condition. Photos helped participants recall more content across all conditions. (B) summarizes the distribution of correctness labels across the conditions. Obfuscation leads to a higher ratio of *semi-correct* and *wrong* answers as opposed to deletion.

Helpfulness scale Participants had to indicate in the *post-questionnaire* if they found the photos helpful in answering the questions on a 5-point Likert scale where 1=Strongly disagree and 5=Strongly agree.

9.2.5 Results

Selection of obfuscation method: Body blurring

The results showed that *body blurring* was clearly favored (Score= 15), followed by (2) face blurring, body silhouette, body point-light, and body inpainting (Score = 9), (3) face pixelating, face masking, body pixelating, body masking, and body bar (Score= 3), and lastly (4) face silhouette and face avatar (Score= 0) indicating they were never selected in the top three methods. Based on that, we decided to choose body blurring to obfuscate the lifelogs from Session 1.

PPM's impact on tendency to change recalled memories

The results show that participants' tendency to change the photos is directly proportional to the quantity of the photos followed by their quality (**RQ1**). Figure 9.5A summarizes the percentage of the reviewed questions in each condition.

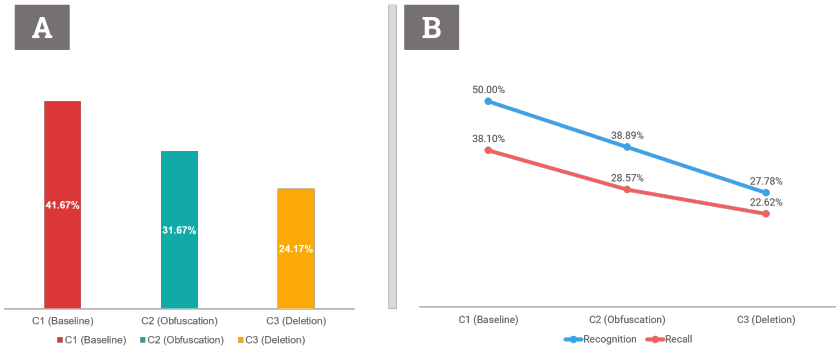


Figure 9.5: Summary of the ratio of changed answers across conditions. (A) shows that participants tend to change their answers whenever they have access to more and higher quality photos. (B) shows that participants tend to change their answers more in recognition rather than recall questions.

41.67% of the answers were updated in C1 (baseline), followed by 31.67% in C2 (obfuscation) and 24.17% in C3 (deletion).

The trend persists if we separately analyze the recall and recognition questions. Figure 9.5B summarizes the percentage of the reviewed questions in each condition within the recall and recognition questions. As expected, participants tended to update their answers after seeing the photos in recognition questions more than recall questions through all conditions.

PPM's impact on the quantity and quality of recalled memories

Figure 9.4A illustrates the average RCS scores of the *pre-questionnaire* (without photos) and the *post-questionnaire* (with photos) for each condition. Similar to the tendency to review the answers, the RCS is more directly proportional to the quantity than the quality of the photos (**RQ2**), and it increased after introducing all the conditions, by 29.46% in C1 (baseline), followed by 14.66% in C3 (deletion), then 12.6% in C2 (obfuscation).

We compared the distribution of the correctness labels within the changed answers per condition and summarized it in Figure 9.4B. Figure 9.6A and 9.6B illustrates the distribution within the recognition and the recall questions respectively. The percentages presented correspond to the ratio within the *changed* answers only.

Correct answers Participants score the highest number of correct answers in the C1 (baseline) regardless of question type. However, as expected, they score

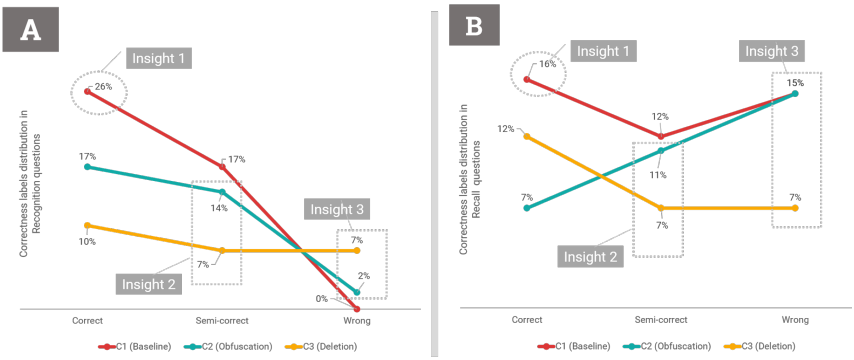


Figure 9.6: (A) summarizes the distribution of the correctness labels accounting only for `recognition` questions, while (B) accounts for `recall` questions. Obfuscation consistently results in a higher number of *semi-correct* answers compared to deletion and wrong answers during `recall` situations. However, it results in fewer wrong answers in `recognition` questions. Thus, obfuscation is good to remember more about a forgotten topic but is misleading regarding details.

higher in recognition questions (26%) compared to recall (16%). However, C2 (obfuscation) outperforms C3 (deletion) in recognition questions (16.67% and 6.67 % respectively) and vice-versa in recall questions (9.52 % and 12% respectively).

Semi-correct answers C2 (obfuscation) results in the highest ratio of *semi-correct* answers compared to C3 (deletion) regardless of question type. However, the trend is more prominent in recognition questions (14.29% and 10.67% respectively) compared to recall questions (7.14% and 6.67% respectively).

Wrong answers C2 (obfuscation) leads to a higher ratio of *wrong* answers in recall questions compared to C3 (deletion) (14.67% and 6.67% respectively). However, the impact is reversed in recognition questions where C3 (deletion) had 7.14% *wrong* answers while C2 (obfuscation) had only 2.38%.

PPM's impact on the lifelogger's confidence about recalled details

We compared the average subjective confidence of the participants about their responses across the conditions. Figure 9.7 summarizes the changes in confidence within each condition. Similar to the tendency to update the answers and

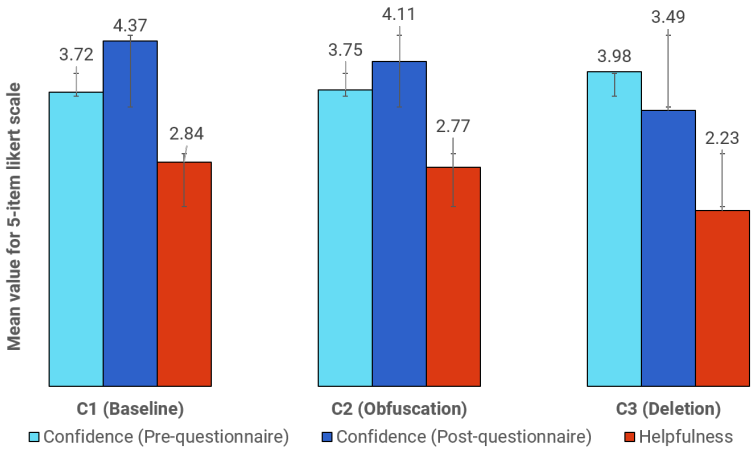


Figure 9.7: Participants' subjective confidence about their final answers increased when they saw more photos. Participants also appreciated the presence of photos as memory cues and found them helpful even if they were obfuscated.

remember more details, the confidence of the participants is directly proportional to the quantity of the photos followed by their quality within both types of questions (**RQ3**). The participants were initially confident about their answers in the *pre-questionnaire*. However, their confidence increased after seeing the photos. Participants were most confident in C1 (baseline) (Mean= 4.37, SD= 0.79) followed by C2 (obfuscation) photos (Mean= 4.11, SD= 0.93). Nevertheless, their confidence decreased in C3 (deletion) (Mean=3.49, SD=1). This could be attributed to the confidence decay within recall questions (see Figure 9.7). It also shows that C1 (baseline) is perceived as the most helpful, followed by C2 (obfuscation). However, C3 (deletion) was perceived as unhelpful.

9.2.6 Lessons Learnt and Takeaways

Our results for the most preferred obfuscation techniques in the context of environmental lifelogging mirrored those of Li et al. obtained in the context of sharing photos [167]. The participants clearly preferred *body blurring* to other face and body obfuscation techniques. They perceived it as a sufficient technique to protect the privacy and preserve the aesthetics although it is known from prior work that it is ineffective in protecting privacy [167, 164, 117, 165]. However, our

results contrast with Li et al. in that participants negatively perceived the *avatar* technique [212, 199], whereas Li et al. [167] recommended it as a good trade-off between efficient privacy protection and positive user experience. This difference is likely due to the context in which the obfuscation was applied, where we considered lifelogs rather than general photo sharing – our participants perceived *aesthetics* to have a strong impact on the acceptance of obfuscation in lifelogs.

Distorted or not, participants find photos helpful

The results suggest that participants subjectively prefer to have more photos even if they are distorted. For instance, they perceived photos as "helpful" in enhancing their recall of memories even when they are obfuscated. This is also evident in the increase of wrong answers when photos are deleted in C3 (deletion) compared to the other conditions. This conforms with the findings of Enns et al. [87] showing that people prioritize regions of clarity in photos as opposed to blurred areas when focusing on content. There is a trend of increased confidence about recalled details in proportion with the quantity of photos shown followed by quality (C1 (baseline), then C2 (obfuscation), then C3 (deletion)). This could be attributed to the presence of other rich memory cues from the scene elements [117, 105] besides the blurred persons.

Recall accuracy mismatches perceived confidence

The perceived sense of confidence and helpfulness of the obfuscated photos does not translate into objective enhancements in the recall quality. The abundance of photos in C1 (baseline) and C2 (obfuscation) encouraged the participants to review and change their answers more frequently. However, this impacted the recall quality negatively as the overall *recall correctness score* of blurred photos was the lowest. Within the changed answers, C2 (obfuscation) produced more *semi-correct* and *wrong* answers than the other conditions. We believe this phenomenon is attributed to the memory interference because of the ambiguous memory cues. We interpret the confusion effect using *Gregory's visual assumption theory* [107]. He theorizes that the visual perception relies on a top-down approach or conceptual-driven processing where we make calculated assumptions to understand what we see based on our expectations, beliefs and prior knowledge. This theory also explains why we can still recognize the photos despite the distortion (blurriness) [121]. Additionally, it explains the prominence of the *semi-correct* answers in C2 (obfuscation) as we approximate the photos to the closest object we know.

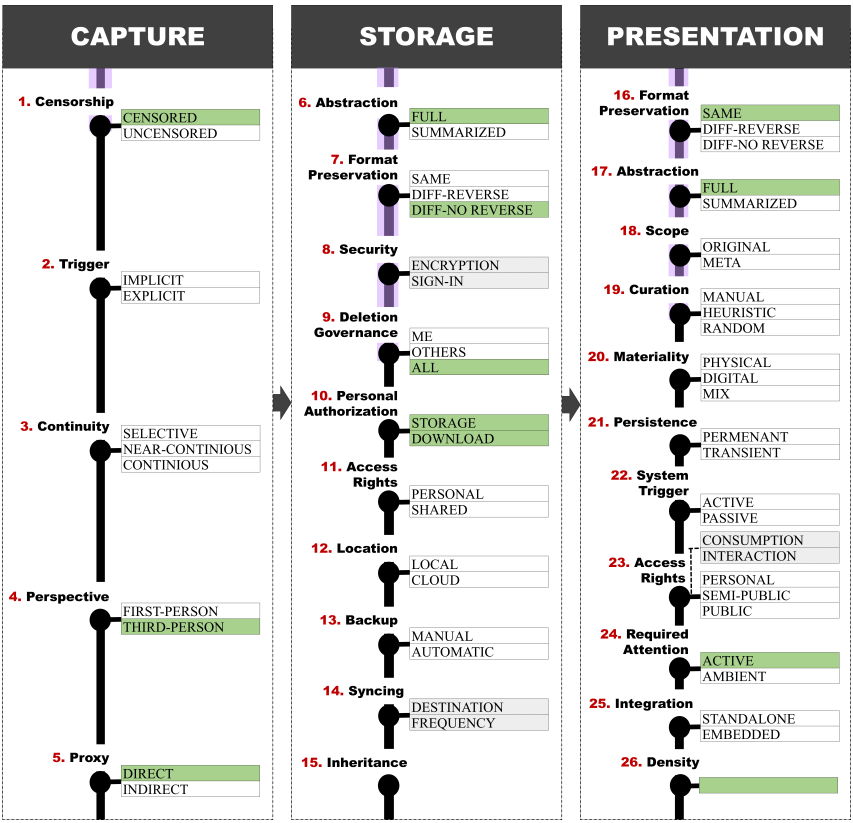


Figure 9.8: Summary of the framework parameters we learnt about through PPM-Cloak project(s). The covered parameters are shaded in Green. We particularly learnt about *(PR 1 and 7)*.

Privacy-aware lifelogs could mislead lifeloggers

We postulate that the participants updated their answers in C1 (baseline) and C3 (deletion) only when they remembered the information without help of any cues, or when they saw explicit cues in the photos, leading to a higher ratio of correct answers. However, C2 (obfuscation) was detrimental to correct recall of details because of guessing and wrongful cuing. This is reflected in the increasing number of wrong answers, particularly in recall context and semi-correct answers during recall as well as recognition. This is likely amplified due to the *retrieval induced forgetting* phenomenon [50], where remembering an unintended piece of

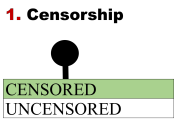
information leads to inhibiting the recall of another requested one. Similarly, it could be explained using Schachter's work [226] about *misattribution*, i.e., the tendency to confuse one memory source with another, and *suggestibility*, i.e., the tendency to mix false suggestions by others with the original memory.

Such effect is particularly promising when coupled with the high confidence rates in the narrated memories. The personalized nature of lifelogs offers a rich opportunity for creating ubiquitous solutions to alter human memory. One could imagine deliberately using blurring to manipulate memories in positive scenarios such as desensitization for high-valence negative memories or negative scenarios such as malicious manipulation of eye witnesses. In conclusion, our results suggest that in accordance with our hypothesis, it is possible to use blurring for memory attenuation. Further research is needed to understand if the attenuation cases include memory implementation.

9.3 Framework Insights

In this section, we map the project findings to the corresponding framework parameters. It shows an example for using *MemAlt* pipeline as a reflection tool to aggregate findings about systems. Figure 9.8 provides an overview on the parameters we learnt about via the project. Table 9.1 summarizes the lessons learnt about each parameter.

Table 9.1: Framework findings inspired by PPMCloak project(s).

Parameter	Lessons Learnt
	**1.** (`CENSORED`) Participants perceive body blurring as a sufficient technique to protect privacy while preserving aesthetics although it is known from prior work that it is ineffective in protecting privacy. **2.** (`CENSORED`) The wrongful or semi-correct remembering when using blurring coupled with the high confidence rates in the narrated memories is a promising and alarming effect as it implies the potential of using obfuscations for memory alterations.

Parameter	Lessons Learnt
4. Perspective FIRST-PERSON THIRD-PERSON	**3.** (THIRD-PERSON) We ensured that every participant appeared at least once in the presented photos. This is important to ensure a baseline of having relatable cues in the photos to all participants. Thus, we opted for temporal deletion and blurring of everyone instead of deleting photos with specific participants. **4.** (THIRD-PERSON) We captured the photos using two opposing cameras covering the experimental area. We alternated the sampling between both cameras to maximize the angle coverage. We wanted to avoid scenarios like capturing the same participant from the back all the time.
5. Proxy DIRECT INDIRECT	**5.** (DIRECT) The collected lifelogs were direct proxies for the events in the first lab session. We tested the position of the camera to ensure it covered the full angle of the experimental area to include as many participants and session cues as possible.
6. Abstraction FULL SUMMARIZED	**6.** (FULL) There is a trend of increased accuracy of memory recollection in proportion with the quantity of photos shown followed by quality (Accuracy rates in descending order: original photos then blurred photos then incomplete dataset from deletion). The trend holds for recognition and recall scenarios. **7.** (FULL) There is a trend of increased confidence about recalled details in proportion with the quantity of photos shown followed by quality. The trend holds for recognition and recall scenarios. (Descending confidence rates: original photos then blurred photos then incomplete dataset from deletion).

Parameter	Lessons Learnt
7. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**8.** (`DIFFERENT-NO REVERSE`) Participants clearly preferred *body blurring* to other face and body obfuscation techniques in the context of environmental lifelogging. **9.** (`DIFFERENT-NO REVERSE`) Face blurring, body silhouette, body point-light, and body inpainting were the second most favoured obfuscation techniques for environmental lifelogs by the participants. **10.** (`DIFFERENT-NO REVERSE`) Face pixelating, face masking, body pixelating, body masking, and body bar were the least favoured obfuscation methods. **11.** (`DIFFERENT-NO REVERSE`) Participants negatively perceived the *avatar* technique in the context of environmental lifelogging. Face silhouette and face avatar were never selected in the top three obfuscation methods.
9. Deletion Governance ME OTHERS ALL	**12.** (`ALL`) Participants' confidence increased after seeing the original and blurred photos. However, their confidence in previously recalled answers decreased in case of C3 (deletion).
10. Personal Authorization STORAGE DOWNLOAD	**13.** (`STORAGE`) Participants were not allowed to contribute further photos to maintain the integrity of central lifelogs. **14.** (`DOWNLOAD`) We restricted the download of the captured photos to ensure the required information decay before testing their memory performance.
16. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**15.** (`SAME`) Participants perceived aesthetics to have a strong impact on the acceptance of obfuscation in lifelogs.

Parameter	Lessons Learnt
17. Abstraction FULL SUMMARIZED	**16.** (FULL) Blurring photos was objectively detrimental to correct recall of details because of guessing and wrongful cuing. **17.** (FULL) Participants perceived photos as "helpful" in enhancing their recall of memories even when they are obfuscated.
24. Required Attention ACTIVE AMBIENT	**18.** (ACTIVE) Participants tended to update their answers after seeing the photos in recall questions more than recognition questions through all conditions. **19.** (ACTIVE) Results suggest that participants updated their answers in C1 (baseline) and C3 (deletion) only when they remembered the information without help of any cues, or when they saw explicit cues in the photos, leading to a higher ratio of correct answers.
26. Density	**20.** (NUMBER OF CUES) Participants subjectively prefer to have more photos even if they are distorted.

9.4 Summary

Privacy concerns of bystanders and lifeloggers is an ongoing challenge to wider adoption of lifelogging. There is rich literature about the impact of obfuscation on privacy protection and user experience. We complement this work by reporting on a two-stage user study (N=12) that investigates the impact of privacy-protection methods on the recall and recognition quality of the memories in the context of environmental lifelogging. We examine two popular methods for privacy protection in literature and practice: obfuscation of persons using body blurring and deletion of private photos as opposed to an original set of photos. Our

results suggest that: (1) participants prefer having more photos even if they are distorted, (2) recall accuracy is highest when viewing original undistorted photos, followed by photos from which private ones were deleted, then finally accuracy is worst when viewing blurred photos, and (3) participants are more susceptible to a misleading sense of confidence in their recalled memories when using blurred images (see lessons learnt about *1. Censorship*, *6. Abstraction*, and *26. Density* parameters). Participants remember more details with high confidence but low accuracy, which means that blurring is good to remember more about a forgotten topic but not to recall accurate details of memories. Our work sheds light on a sensitive trade-off between protecting the privacy in lifelogs and accidentally undermining the lifelogs' potential as a memory augmentation prosthetic. The current results suggest that our hypothesis is possible in that we can use blurring for memory attenuation and potentially implementation. However, further research is still required to understand the limitations and implications of deliberate alteration of specific memories.

Chapter 10

Shared Memories on Social Media

In this chapter, we discuss the user expectations of how their curated memories on shared systems are used by other users and by the systems themselves. We use social media as an example of MACS that can alter memory ambiently or actively. We chose social media as an example for personalized digital platforms because it is rich in highly personal and custom content. Additionally, it is widely used across different user groups and steers intriguing discussions and controversy about its impact cuing offline interactions. In this context, we consider any content explicitly shared or interacted with on social media as a cue to a memory and refer to it here as *shared memory*. We focus on discussing automatic utilization of the shared memory by other users and the intelligent systems without asking for explicit consent about a specific cue. To this end, we reflect on two scenarios to highlight the importance of the topic:

Privacy breeches in Facebook (FB) women-only groups Through an auto-ethnographic account, we reflect on the sharing behavior in famous women-only FB groups in the Middle East. We focus on the consequences of sharing sensitive content beyond the scope of the group. We reflect on the user's trust expectations in handling their memories when sharing with a group of strangers.

Surprising intelligent interactions on FB Through a survey, we reflect on the user's reactions towards tailored smart content on FB derived from their digital footprint in the platform and elsewhere. We reflect on the user's attitude towards the platform in the presence of such interactions.

We conduct both projects in Egypt. We chose this user group as literature focusing on privacy and behavior on social networks is underrepresented in non-Western-Educated-Industrialized-Rich-Democratic (WEIRD) countries [122]. We use FB as an example medium because it is widely used in our user group as 35 out of 50 million of the Egyptian internet users are active Facebook users [183, 238]. Additionally, it supports several media formats, thus rendering rich memory cues.

Parts of this chapter are based on the following publication(s):

- P. Elagroudy and M. Saleh. We have each others' backs: A study on women only facebook groups. In *Adjunct Proc. CHI Workshop on Sensitive Research, Practice and Design in HCI*, 2019
- P. Elagroudy, M. Saleh, C. Sturm, and A. Schmidt. How do users expect their smart memory vaults to utilize their shared memories? In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA, 29 April 2022 - 5 May 2022*, pages 448:1–448:6. ACM, 2022

10.1 Utilization by Other Users

Online support groups have existed on Facebook for over 10 years and have proven to help individuals in distress. Some examples in the health domain include support groups for breast cancer [30], autism [216], and weight management [248]. Recently, there has been a rise in the number of FB support groups acting as safe places for female members only. For example, Pruchniewska investigated women-only Facebook groups for career advancement [206]. The participants reported that the absence of men in the group has helped them open up about their experience to other women without being "bolstered" by men. One participant reported that the sharing "ended up in an outpouring of similar stories, which gave me the confidence to post more publicly". The sharing model on such groups relies on the trust that members will not share the content on the group outside

its scope. In this account, we focus on the pattern of sharing one's sensitive memories to support another member after sharing a similar experience without considering potential privacy breaches by other members.

In our work (**E-Ally** project), we highlight accounts of this pattern within the user group of women from the Middle East and North Africa (MENA) region, specifically from Egypt. We chose this user group as it represents non-WEIRD user groups and because the highly collectivist nature of the Arab culture encourages women to befriend other women such as neighbors and relatives in their social circles [61]. We selected Egypt particularly to capitalize on the accessibility of this unique user group to the researchers. Our membership and administration of several popular groups in the geographical area enabled us to create an auto-ethnographic account of the problem highlighting the unique sharing patterns of this under-explored user group. This project ignites the discussion about culturally-sensitive User Experience (UX) that can empower marginalized user groups.

10.1.1 Research Context

Women-only Facebook groups have been one of the most trending social network phenomena in Egypt in the past five years. They evolved from simple chatter between hundreds of members to communities exceeding a half million members discussing sensitive personal problems. While these groups provide a well-needed haven for women to capitalize on their collective expertise, new under-investigated threats of privacy breaches have surfaced. The members are comfortable sharing their private issues with hundreds of thousands of strangers with a fake sense of security that the group is trusted. However, the privacy breaches have led to severe social consequences like divorce in some cases.

The researchers in this project are members of over 40 women-only Facebook groups of different sizes and objectives. We are also administrators to several groups (size=2k+ members). Below are common observations across the groups to set the scene for the reader to the dynamics of the privacy breaches.

Group Structures

We identified two types of groups: (1) topic-based groups similar to interest groups, and (2) generic groups acting as a communication hubs about any topic. The groups are either private or secret (by invitation only) to enable the gender filtration process. Common themes for groups with specific focus are: beauty

and shopping, cooking, health and well-being, and relationship counseling, particularly for marital problems. Groups can discuss culturally-sensitive content such as challenges of relationships, religious opinions and debates, and sexual harassment. Group sizes vary in nature; they can be under 1000 members to over 500 thousand members. There are two models for posting memories on the groups: (1) from the member's personal profile, or (2) via an anonymous link to simulate a "confession" session setup, whereby the content is posted later by the group administrators. In the latter type, members could choose to respond with their real identities, anonymously, or by creating fake profiles to protect their identities when giving sensitive advice. It is worth noting that Facebook recently introduced a new feature for anonymous posts and comments on groups. However, it was not available while working on this project. The below sections give an outlook on recruitment strategies in the groups and shows how members gain the trust of other women in the group.

Governance System

These groups are usually moderated by one or more administrators. In most groups, the administrators must approve each individual post on the group. This gives the administrators a powerful position to steer the discussion topics of thousands of women and shape their sense about the frequency of existing problems based on the selected posts. We consider this scenario a variation of ambient memory reformation. Each group is governed by a set of rules. Group rules are written statements requesting all members to respect each other and maintain group privacy. By joining a group, one is assumed to abide by the group rules without legal means to prevent the breaches.

Members' Selection Criteria

The objective of these groups is to bring like-minded women who are interested in similar things together. The main criteria is ensuring that the addition request is from a woman. This is done via non-conclusive checks such as rejecting recently created profiles, looking for mutual friends from older trusted group members, and checking the other groups the person has joined. This has sometimes already led to the addition of fake profiles from males. Another criterion in Egypt of "like-mindednes" is having members of the group being from the same Socio-Economic Status (SES) and/or political background. While some groups are more forward about this saying in the description, "we only accept A-class society members", most of the groups practice this by accepting only select members.

Commonly used ways to detect the SES of a member is by their profile picture, university or mutual friends.

Group Dynamics and Building Social Rapport

In each group, there are exceptionally active members who are well-known. Their advice is taken more seriously and their posts have more interactions. They are either group administrators or what Facebook refers to as "top contributors". Most of these women have developed personal relationships beyond the limits of the group. While these groups foster a supportive environment, they are still not ideal. There are posts where women strongly attack or mock each other. These posts seem to gain high popularity mostly by members tagging their other friends to come and "watch" the comments. This phenomenon is common and administrators usually react by disabling comments and requesting members to adhere by the stated group rules then muting/blocking the offenders.

10.1.2 Examples of Privacy Breaches

Groups define privacy breaches as showing the group content to others outside the group, especially via screen shots. This could be done deliberately to publicly share the content over social media or with other friends or via accidental shoulder surfing especially by male acquaintances. The breaches are still shocking to group administrators despite being observed in many groups before. Administrators often react strongly by blocking and reporting the member. Some resort to public shaming and defamation, which is a dire punishment in the Arabic culture. We present below two real stories to convey the consequences of the breaches to the reader in this social context. These are examples of common breaches. The groups' names are kept anonymous to protect the members' identity.

Group A has ca. 30k members. They support brides through their wedding preparations. A typical post would be to ask about places to buy dresses. However, after building social rapport, it became a safe support group for brides feeling pressured or lonely. The result is occasional personal posts such as "I had an unpleasant experience with my in-laws yesterday". An example of sensitive content is women sharing their own photos in revealing clothes during bachelorette parties. The photos would normally be shown only to trusted known women as they can cause defaming if released. Despite sharing the content with 30k strangers, the women are shocked when the photos are shared outside the group.

Group B has ca. 120k women. They discuss relationship issues and help women get advice from more experienced women. Sensitive topics discussed include infidelity, sexual problems, family issues and other taboo topics outside cultural norms. Thus, it follows the "confessions" model. Surprisingly, many of the comments on the groups also reveal intimate and personal details about members' lives, leading to severe social repercussions. In an unfortunate incident, a member wrote an offensive comment about her husband, assuming this was a confidential women-only space. The woman's sister-in-law took a screen shot from the comment and showed it to the member's husband, which consequently lead to divorce. The group publicly defamed the sister-in-law for breaking their "code".

10.1.3 Lessons Learnt and Takeaways

Social networks have given a platform for strangers to connect, help and support one another. They are an accessible form of MACS helping shape the awareness of masses about current topics and providing a vault for sharing their memories. Online groups have given voice to under-represented populations to discuss their issues and create support communities. Like physical social interactions, individuals from marginalized communities are more susceptible to the consequences of social rejection and defamation. Thus, protection mechanisms like alias names, private groups and untraceable content are heavily utilized in social media interactions. As HCI researchers, we might have limited power to alter such social arrangements. However, it is our role to provide the enabling technologies to support safer digital interactions with human memories.

Through this autoethnographic account, we highlight the phenomenon of sharing sensitive content with masses of strangers in women-only groups following the physical metaphor of trusted sharing within a group of friends. We particularly focus on the paradox of sharing sensitive content without considering the consequences of privacy breaches despite their abundance. Our observations show that participants in women-only online groups in Egypt expect other members to abide by social norms protecting the privacy of their shared content. However, current interfaces do not support users in enforcing such assumptions. They also show that the members underestimate the reachability of their content to other fellow members they know offline. It would be particularly beneficial to further investigate how the perceived privacy of a memory changes between the digital and physical world. For example, a person would not publicly talk about their problem in front of 100 people in a restaurant despite the ephemeral nature of their speech. However, they share it in a documented medium with several thousand

members online while exposing their identity to their social circles. Thus, as HCI researchers, we have an open opportunity to optimize the UX through new interaction paradigms to protect vulnerable communities.

10.2 Utilization by Smart Systems

In the previous chapters, we discussed MACS using ambient models for altering memories. We consider smart social media interactions one form of such models. The interactions and recommendations have recently been becoming more tailored and personalized using the digital footprint of the users to better understand their needs and likes. Users provide social media with a digital trail as they use it as semi-public memory vaults to share and add cues to their memories and interests at given points of time. The algorithms running such platforms use the holistic user data to draw accurate inferences about human behavior and to provide personalized digital services such as advertisements and product recommendations. However, the recent international public anger and surprise about such algorithms cuing offline interactions (e.g. influencing voters [44]) shows a lack of the public awareness about the collected data and its repercussions. Although the mystery behind AI algorithms contributes to its success in creating seamless interactions, the emerging field of Explainable AI(XAI) challenges this concept (e.g. [110]). Further work also suggests that simplifying privacy policies to the average user can result in more informed decisions and interactions (e.g. [246]). Thus, we are interested to investigate the trade-off between black-box vs. transparent AI on the user experience in MACS.

To achieve this goal, we present the **PandoraBox** project. In this work, we aim to understand this trade-off by investigating user perceptions about smart behaviors of social algorithms. We use Facebook as a common example of an AI-powered social media platform to reflect on surprising interactions for Egyptian users. Specifically, we look at the effect of the surprises on the affect and the behavioral change resulting from using the platform. *Surprising incidents* within our context are defined as unexpected behaviors on the platform regardless of their connotation. This means that a user can be excited about a surprising incident or appalled by it.

We conducted an online survey (N=53) using critical incident recalling to categorize incidents, their reasons and impact on platform usage. Our results suggest that current practices regarding data usage do not lead to informed consent and make users feel exploited by the platforms. Additionally, we found that negative

platform perception does not translate directly to an active reduction of platform usage. This could be attributed to the collectivist nature of the Egyptian culture that emphasizes the need to stay connected over any other value. Our work informs the community about the users' expectations regarding their privacy and their perception of customized content on AI-powered social media platforms. It also motivates further explorations of user expectations within diverse cultures.

10.2.1 Methodology

We investigated *the impact of surprising intelligent Facebook behaviors on the usage pattern and the affect towards the platform*. To achieve this, we used a critical incident-recall qualitative questionnaire to reflect on a specific surprising incident when using Facebook, its consequences, perceived reasons and the associated affect with it.

Research Method: Online Survey

The survey was composed of three sections. Table 10.1 shows sample questions.

1. **Demographics** We inquired about nationality, length of Facebook usage and Computer Science expertise. The demographics helped us dissect and group the qualitative data.
2. **Critical incident report** We asked the participants to reflect on a specific surprising incident mentioning why it was surprising, its consequences and their interpretation of the reasons for it.
3. **Attitude towards platform** We used SAM to evaluate the affect of the participants about the incident [98]. Participants were asked if the incident changed their usage patterns towards Facebook, and if they considered the incident to be a privacy invasion.

We reduced the *self-report bias* by using neutral connotations about the platform and the incidents to avoid cuing the participants. Additionally, critical incident recall has been shown to reduce inaccuracies in self report as it focuses on a single incident rather than open ended questions left for a participant's emotion and interpretation at the time of answer [92]. Finally, we encouraged the participants to report more than one incident consecutively after reporting all details of the previous incident, to reflect holistically on the platform experience.

Table 10.1: Overview of the survey questions.

Type	Question
Open-ended	Please complete the following sentence and use this incident to answer the rest of the survey. Facebook uses our data or actions in different ways. I was surprised when I saw that Facebook ...
Likert-Item	On a scale of 1 (not surprised at all) to 5 (extremely surprised), how surprised were you by this incident?
SAM scales	What were your feelings after the incident?
Open-ended	Do you consider this incident to be a privacy invasion or not? Please answer with a yes or no then justify your answer.

Procedures

After obtaining their consent, participants were asked if they were Facebook users. Only Facebook users were allowed to proceed with the questionnaire. They were then directed to the questionnaire that was divided into three pages corresponding to the parts without adding a title to the questionnaire page. By the end of the questionnaire, we asked the participants if they would like to report further incidents. Participants who agreed were redirected to the beginning of the questionnaire while others were directed to a page offering them to voluntarily participate in a raffle for compensation.

Participants and Recruitment

We distributed the questionnaire through online channels such as popular Facebook groups to reach Egyptian users. We received a total of 57 responses, whereby four entries were excluded as the answers did not reflect on a specific incident (N=53). Participants were compensated with a raffle for a shopping voucher. There were 11 males and 42 females in the final corpus. Participants were aged between 20–56 years old (mean= 31.2, SD=10.75).

Analysis Methods

We used thematic analysis to analyze the qualitative data. Two researchers independently open-coded 20% of the entries using inductive coding techniques. In each incident, we were looking for a category for the surprising incident, its consequence on the user, and why the incident was surprising. Next, the tags were discussed and grouped into a single coding tree focusing on values coding to identify themes of incidents. Afterwards, one researcher tagged the full corpus using the defined tags and marked entries that required new tags. Each entry was

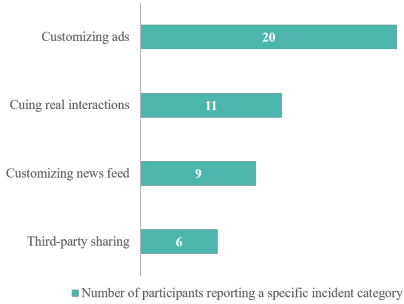


Figure 10.1: The emerging themes from the reported incidents sorted descendingly by incidental frequency.

assigned exclusively to a single tag. The new tags were discussed between the two researchers and the controversial entries were categorized collaboratively. Code instances were counted to define emerging themes (values coding). We did in-vivo coding and considered quotes from codes with at least two instances. We also did versus coding over the defined codes with respect to the demographic data we collected to identify differences across the user groups. We used medians to evaluate Likert-items data such as the magnitude of surprise and SAM scales.

10.2.2 Results

We reflect in this section on three points: (1) categories of surprising incidents on FB, (2) impact of the surprise on the affective perception on FB, and (3) users' perception of the incident with respect to privacy violations.

Categories of Surprising Incidents

We describe in this section the common types of surprising incidents that occurred on the platform and reflect on the top two reasons of the surprise, the consequences of the incident, and the associated affect and perception of the incident. Figure 10.1 summarizes the frequency of the incidents. Table 10.2 summarizes the qualitative data about the top categories.

Personal Customization of Advertisements This category was reported the most in the survey data. Participants commented repeatedly on showing advertisements based on search activities in other platforms, conversations with

Table 10.2: Justification for why the incident was surprising and the consequences of the surprise in each category of the incidents.

	Customizing ads	Cuing real interactions	Customizing news feed	Third-party sharing
REASON OF SURPRISE				
Personal data exploitation	■			■
Lack of informed consent	■			
Inexplicable platform behavior		■	■	■
Out-of-scope usage objective				■
EFFECT OF THE INCIDENT				
Awareness of platform data usage pattern	■		■	
Discussing phenomenon with others		■		
Negative company image	■	■		■
Reducing platform usage			■	■

friends on Facebook, or real verbal communication next to mobiles. For example, **P10** commented that *"It has personalised ads to what I have looked up recently, even on other platforms. Sometimes the ads are relevant to something I have talked about near my phone, but never even searched"*.

Participants were surprised mostly because they perceived it as exploitation for their data (7 participants). **P10** explains *"it seems like I'm being spied on, then manipulated by having suitable ads for my recent interests so I would spend money"*. Another theme was the lack of informed consent (6 participants), justifying why participants felt exploited. Such incidents resulted in a negative company image (10 participants), and increasing the awareness of the participants that their data was being used (3 participants). However, a minimal number of participants took an active action and reduced their platform usage (3 participants).

Cuing Interactions with People This category covered incidents of automatically suggesting new friends on the platform and limiting or extending their interactions with existing ones (11 participants). For example, **P7** commented that the platform *"removed members from my makeup group by itself"*. Alternatively, **P20** commented that Facebook *"pops up people I may know instantly while I am just sitting beside them in the same place without even really knowing them"*.

The incidents were surprising because the participants did not understand the rationale behind them and how they were inferred from their platform interactions (7 participants). For example, **P50** comments on a new friend suggestion saying

"the person is nowhere near my circle or close to the people that I know and the number of mutual friends is very low". There was no prominent trend in the consequences of these incidents. Consequences included negative company image (4 participants), and starting conversations with others about the phenomenon (2 participants). However, the suggestions rarely resulted in creating a new virtual relationship (2 participants). We informally observed through our prior research that laymen are intrigued specifically by understanding how the suggestions are formed for new relationships and seem to relax and enjoy the potentially simple heuristics like geographical co-location. However, such results show that those focused interactions on the platform in the current mysterious form do not necessarily yield the expected results of increasing virtual bonds.

Sharing Personal Data with Third-Party Entities This category covered reports about utilization of platform data for the benefit of the third parties. It occurred repetitively (9 participants). However, the reported incidents were short and vague compared to the other categories. For example, **P2** said that the platform *"was selling data"*. Terms like "selling", "using", and "sharing" data were commonly used in the incident report.

Participants could not articulate clearly the reasons for finding those incidents surprising. Thus, there was no prominent trend and the reasons included inexplicable behavior from the platform, defying the platform objective, and exploitation. For example, **P19** said *"I was not aware that Facebook can monitor my actions"* while **P2** commented that *"it (selling data) is a big risk considering the fallout and the bad publicity"*. Similarly, there was no clear trend in the perceived consequences of the incidents. They varied between increasing the negative company image without behavioral change (4 participants) and reducing platform usage (4 participants). Overall, participants were not aware about data sharing policies, which is a challenge for informed consent.

Personal Customization of News Feed This category covers incidents about altering the amount of curated content from particular people and/or topics in the news feed (6 participants). The majority of reports were about topic customization rather than people. For example, **P8** explains *"I was texting my friend on messenger and I kept seeing posts of the same topic on my News Feed"*.

The primary reason for the surprise was not understanding the rationale behind the customization (3 participants), similar to the "cuing interactions with people" category. Terms like "bizarre" and "creepy" were frequently used to describe the interaction. Due to the limited number of reports in this category, other reasons like losing autonomy over displayed content and lack of informed consent occurred only once. There were no clear trends in the consequences of the

incidents. Examples included increased awareness without reported behavioral change (2 participants) or active reduction of platform usage (2 participants).

Incidents' Categories from a Demographic Lens

This section correlates the gender, age, and computer training with the categories of the reported incidents. We are cautious in speculating about those trends because of the unbalanced sample size. However, we report them to nudge further future investigations in this direction.

Gender We observed that no males reported incidents related to cuing interactions with people, while 26% of the females did. Additionally, 45% of the males reported incidents related to sharing data with 3rd parties, while only 10% of the females reported about this category. This indicates that the females were more sensitive towards surprising social interactions while the males were more sensitive towards interactions resulting in monetary gain for the platform.

Age The (40-60 years) segment mostly reported about advertisement customization. The frequency of reports shows the lack of awareness about personalization techniques in older generations. However, the (30-50 years) segment focused their reports on sharing data with 3rd parties. This may be attributed to the younger generations being more indulgent in utilizing technology while being exposed to abstract news about malicious use cases.

Computer Science Training The most prominent finding about groups with higher training is that they did not react aggressively to the surprising incidents, as if they were expected. For example, **P49** when asked about the consequences stated *"Nothing, it's fine for data analysis"*. This could imply the importance of technical literacy for educated guesses about the algorithms' heuristics.

Affective Perception of the Incidents

This section covers self-reported scales about how surprising aforementioned incidents were and the recalled affect after. Table 10.3 summarizes the results.

Surprise Magnitude Participants were surprised equally (*Median= 4*) about customizing the advertisements, sharing data with third-parties and personalization of the News Feed. However, their reaction was neutral (*Median= 3*) towards cuing interactions with people.

Table 10.3: Summary of the affect towards intelligent interactions on Facebook in Egypt. Participants were surprised about direct personalization of platform content compared to cuing offline interactions. They were particularly unsatisfied by advertisement manipulation and utilizing their data outside the platform. They also felt strongly about sharing their data with third parties and cuing their offline interactions such as proposing people they may know.

Metric	Customizing ads	Third-party sharing	Customizing news feed	Cuing real interactions
Surprise	4 (surprised)	4 (surprised)	4 (surprised)	3 (neutral)
Pleasure	3 (unsatisfied)	2.5 (unsatisfied)	2 (neutral)	2 (neutral)
Arousal	3 (neutral)	3 (neutral)	2.5 (neutral)	2 (dull)
Dominance	3 (neutral)	2 (powerful)	3 (neutral)	2 (powerful)

SAM - Pleasure This metric describes the level of pleasure (valence) associated with the reported incident. Customization of advertisements (*Median= 3*) and sharing data with third-parties (*Median= 2.5*) resulted in an unsatisfied reaction on the pleasure scale. On the other hand, customizing the news feed (*Median= 2*) and cuing interactions (*Median= 2*) led to a neutral reaction.

SAM - Arousal This metric describes how interesting the incident was perceived. Participants were neutral about customization of advertisements (*Median= 3*), sharing data with third-parties (*Median= 3*), and customizing the news feed (*Median= 2.5*). However, they found cuing interactions with people (*Median= 2*) to be dull.

SAM-Dominance This metric describes the prevalence of the reported emotions about the incident. Participants had powerful views on sharing data with third-parties (*Median= 2*) and cuing interactions with people (*Median= 2*), unlike the other two neutral categories (*Median= 3*).

Users' Perception of Privacy Violations

Figure 10.2 summarizes the results. Forty seven participants mentioned that they perceived the incident as a privacy invasion while only six participants mentioned that they did not. Top reasons included unauthorized use of personal content in an unintended context. For example, **P50** stated that *"it felt like they know what I do and where I'm at always and acts upon it, an app should have no access to such information, it's there for me to use, not for it to use me"*. Others reported that some data was sensitive because they were unaware that "private" resources are being used. For example, commonly reported cases included the use of mics

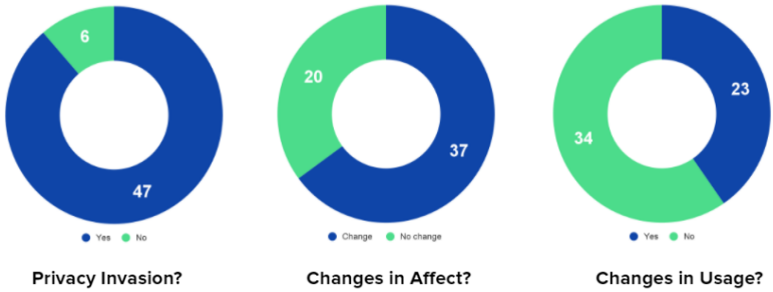


Figure 10.2: Summary of users' privacy attitude towards the incidents.

during conversations or Google search queries to access information and generate advertisements. This leads to cautious usage and sometimes behavioral changes in the usage patterns due to uninformed consent.

Thirty seven participants experienced a change in affect towards the platform while only twenty three reported a change in their behavior on the platform. This shows a natural sequence of filtration from moving beyond a single incident to an emotion to an actual behavioral change. This also shows that the number of users on the platform does not directly reflect user satisfaction. The most prominently reported changes in attitude were reduced feeling of privacy and reduced trust.

Participants who changed their usage behavior reported decreased sharing about specific topics or limiting sharing objectives to texting objectives. In addition, they also reported priming towards a specific topic or person. For example **P25** said *"I became more alert of the things that come up on my news feed now"*.

10.2.3 Lessons Learnt and Takeaways

In this project, we report on our analysis of 53 survey responses to understand the impact of MACS utilizing the users' data to create smart interactions without their informed consent. We specifically looked into the users' perspective in the context of tracked data and interactions on social media, and investigated the impact of intelligent FB behavior on the usage pattern and affect towards the platform. We identified four scenarios where users find the interaction "suprising": personalization of advertisements, cuing offline interactions, cued curation of news feed and sharing their data with third parties outside the platform. It is

important to note that the connotation of a "surprise" in our context is neutral. Our work contributes to the discussion of how to communicate the decisions of smart systems to users to maximize the quality of their user experience. We reflect below on the results summarizing the takeaways into three points:

Affect and Behavioral Change are Independent Participants were more susceptible to changing their behavior when they perceived direct threat to their data like sharing it with 3rd parties, or if their curated content was directly affected like customizing their news feed. However, the low percentage changing their behavior despite the relatively high percentage reporting negative affective responses shows that the number of users on the platform does not directly reflect user satisfaction.

Sharing Data to Generate Revenue is Misperceived Sharing data whether by providing it to third parties or through customized advertisements requires further research into effectively involving users, as this resulted in the strongest negative affective responses. We speculate that the users negatively reacted towards actions that were perceived to bring direct monetary value to the company without involving them. This could also be explained by linking it to Hsu et al.'s work [134] showing that users felt they could not control the privacy settings for customizing ads, even though they felt comfortable adjusting the settings for the news feed and notifications.

Identify Relevant Personalization Use Cases The low arousal in all categories may imply low interest of users in detailed personalization compared to the emphasis of the technical community on enhancing its accuracy. In particular, cuing interactions with people was not positively perceived by the users despite being highly detectable by them.

10.3 Summary

In this chapter, we reflected on the user expectations from fellow users and MACS regarding utilization of their memories. We picked the specific context of social media as an example for MACS that is already widely adopted by users. Our work was conducted using Facebook in Egypt as an example of a widely used platform offering several types of of memory cues and smart interactions. Through an auto-ethnographic account and an online survey, we answered **RQ5**: *How do users expect their shared memories to be used on MACS?*.

We learnt that users do not fully realize the reachability of their shared content. They translate offline social constructs such as confining their information to other friends and trusting them into the context of sharing with strangers in online support groups. This behavior causes severe offline repercussions to users from vulnerable populations. Thus, there is an open research opportunity for HCI researchers to redefine safe interactions for sharing memories on such platforms. We particularly encourage researchers to look into the behavior of special user groups such as females in the MENA region. The work is timely as FB recently, for example, introduced "anonymous posts and comments" to support groups.

We also learnt that although utilizing user data is part of the initial user-agreement and is a common business model for providing free digital services, users are still apprehensive of it. Thus, further research explorations are required to define sensitive data snippets that should not be utilized. We also noticed that personalized content acts as a form of ambient memory augmentation. Users are able to recall past interactions on the platform or shared content that trigger the personalization. Thus, they remember more about what they are doing. We also observed that cuing interaction with people through features like "people you may know"[27] could become a form of ambient memory implantation giving a fake sense of knowing the person even though the user might have never met them, because of the repetitive presentation of their details. Additionally, we learnt that users were not excited about personalized interactions even though they were able to detect them. Our work is a step forward in highlighting challenges related to data governing to increase the social acceptability of MACS.

[27] A feature that frequently proposes people that the platform thinks should be in your social circle by showing the name and photo of the person and the common friends.

V

Research Implications

Chapter 11

Design Guidelines for MACS

In this chapter, we present nineteen generic design guidelines for designing MACS. Figure 11.1 (at the end of the chapter) summarizes the contribution of the use cases' projects in learning about the parameters of the *MemAlt* pipeline. Appendix A consolidates all the insights about the *MemAlt* pipeline from the research projects and groups them by parameter. We group the guidelines into six themes: (1) recommendations for niche use cases for MACS, (2) recommendations for setting up the capturing system for MACS, (3) recommendations for selecting the appropriate proxy cue for a memory, (4) recommendations for selecting cues to present in MACS, (5) recommendations for depicting the selected memory cues, and finally (6) storage recommendations for the collected datasets.

11.1 Use Cases for MACS

1. Daily Reviews are Not Enough for Memory Augmentation Short generic reviews of daily activities in the form of time lapses are not sufficient for enhancing recall. This is particularly true for reviews showing crude cues like lifelog photos spanning the day without further compilation of high level findings findings such as "Your day today was busy because you did 12 things". Thus, designers need to carefully consider the required repetition threshold of the cues to achieve results of implicit memory augmentation. On the other hand,

such reviews could be useful to support reflection and autonomy. (*Derived from Appendix A insight(s): 49,97,98,99*)

2. Design Augmentation MACS for Progressive Events and Imparting Knowledge Users frequently request memory augmentation MACS for two main scenarios: (1) reviewing consecutive events spanning larger time periods to facilitate receiving new relevant information, and (2) learning new skills. Common examples for the first scenario are systems reviewing the past meeting minutes in ongoing projects, tracking of body progress, and tracking of productivity within a certain project or period. Common examples for the second scenario are compilations of past experiences of the user or other users to quickly impart knowledge about cooking, scientific material and extra curricular activities. Designers can capitalize on that need and build niche active memory augmentation MACS. Advertisers and content creators can also capitalize on it and build ambient memory augmentation solutions. (*Derived from Appendix A insight(s): 60,61,62,63,65,66,71,72,73,74*)

3. Use Parallel Reviewing for Reflection and Imparting Knowledge We recommend using parallel reviewing of full longitudinal pictorial datasets for active memory augmentation. Parallel reviewing of such datasets promotes a sense a productivity, and enables users to draw new conclusions about how they spend their time and quickly recall forgotten errands, unlike sequential reviewing. Thus, it is best suited for memory augmentation scenarios; especially ones related to quickly imparting knowledge about a new topic or reviewing content from longer periods of time. Sequential reviewing is better suited for daily reviews, while parallel is better suited for meta reflections. Speed sequential reviewing (like the **LifeRewinder** system) offer a good trade-off between both worlds for reviewing activities from datasets for short-term periods (order of days). We encourage designers to capitalize on the strong cognitive powers of people in finding patterns and design smart visualizations for parallel reviewing. (*Derived from Appendix A insight(s): 60,61,62,63,64,90,91*)

4. Show Pictorial Lifelog Samples in Debriefings Lifelogging near-continuous capturing devices like cameras are still not widely used commercially. Thus, participants cannot imagine the capturing range of the cameras. They often believe it mimics their vision range or that the resolution is too low and will only show prominent people and objects. Both assumptions are misguided. This often causes disappointment when they realize the camera view differs from their perspective and their are missed cues. On the other hand, it causes discord especially in the beginning of studies when they capture sensitive information, particularly from screens in front of them. For example, our participants were

surprised they could see their social media content in the captured lifelogs. The mismatched expectations resulted in general apprehension towards sharing the lifelogs. Showing participants previously captured cues like photos is not enough to convey the expectations and the limitations of the experience. Thus, we suggest to either allow for a test run period in the beginning of studies where participants try the device and see the data before starting memory studies. Alternatively, a researcher could design a longer debriefing session and allow the participant to use the device during the session then review the data with them. (*Derived from Appendix A insight(s): 15,33,39,42,49,79*)

11.2 Capturing Setup

5. Design Inclusive Cameras and Capturing Devices The current chest-mounted camera designs negatively interfere with the users' daily habits and are often occluded. This is particularly true for users with longer hair or larger busts. Thus, it mostly puts women at a disadvantage. For example, long hair covers the lens. Thus, female participants in one of our longitudinal studies complained about having to change their hairstyle to participate. Similarly, they commented that they could not wear the camera with a scarf in winters or with loose t-shirts as it would keep moving. The research team in a past study also observed that females with full busts had more difficulty in capturing quality photos, as the cameras tended to capture ceiling views rather than first-person views. Such limitations constrain the adoption of the technology as its disrupts the quality of the captured cues. Additionally, it complicates the recruitment of participants in lifelogging studies. (*Derived from Appendix A insight(s): 10,11,12,79*)

6. Enable Capturing Governance for Known Bystanders MACS supporting automatic (near)-continuous capturing should include a mechanism to allow a user's acquaintances to be removed automatically from the dataset. This is particularly relevant to memory augmentation systems as they capitalize on collecting as many cues as possible. However, careful designs should be adopted to minimize accidental ambient memory reformations. Co-participants do not pose a problem as the users usually discuss the decision of capturing data around them as they are frequently in the capturing range. However, the lack of autonomy for other known bystanders such as friends and colleagues raises interaction problems and creates tension between users and their social circles. Participants would like to respect the privacy of other individuals they are sharing the space with. However, as the cameras are designed on purpose to be ubiquitous

and forgotten, it becomes increasingly challenging to remember to take it off. Thus, we recommend including techniques that alarm new bystanders that they are being captured. One possible approach is adding an alarm in the camera (e.g. a blink or beep) whenever a new person is detected in the capturing range for a certain time threshold. This approach handles the capturing device as a social being introducing itself to new members of the group and can encourage interaction with the capturing experience. This approach builds upon prior work that indicates that users treat devices like TVs as social beings and exhibit similar reactions when it comes to motion and social cues as they do with real people [211]. (*Derived from Appendix A insight(s): 1,2,6,8*)

7. Third-Person Captures are Richer but First-Person are More Natural First-person capture is more likely to miss capturing the user's actions such as in the case of a chest-mounted camera capturing the view in front of the user focusing on the bystanders. However, it is also possible to capture the user's actions in situations like a fitness tracker capturing the heart rate and exercising activities of a user. On the other hand, third-person captures are more likely to capture the user's action. Thus, they provide a more objective and holistic view of an event. Nevertheless, they offer a less natural view compared to how we remember events as the first-person capture is closer to what a person sees and experiences during an incident. We recommend using third-person captures from environmental lifelogs as memory cues for memory augmentation in scenarios of shared recollection of memories of groups. The reason is they provide a unified type of artifact between all group members to facilitate discussion and reminiscence while providing rich details including everyone. (*Derived from Appendix A insight(s): Meta observation from several studies*)

11.3 Proxy of Captured Cues

8. Use Direct Proxies for Informational Ambient Alteration Direct proxies (e.g. photos or audio recordings of a particular incident) are more preferable than indirect proxies for ambient memory augmentation about external domain-based information (e.g. trial of new activities of study programs). An example is if we want to encourage a group of students to join the university musical, it is better to show a group photo of their friends rehearsing rather than an unlabelled audio recording of a song from the rehearsal. The directness of the proxy simplifies registering it without requiring focused attention. Similarly, direct proxies are preferable for ambient memory implantation to provide a base-

line of clear salient cues from one memory that could be misattributed to other relevant memories. (*Derived from Appendix A insight(s): 15,17,18,19,21*)

9. Use Indirect Proxies for Privacy Protection of Shared Memories Direct proxy cues are clear to review even for individuals who did not attend an incident. However, indirect proxies are like secret codes. They require contextual prior knowledge of the memory to understand them. Thus, they propose using indirect cues for memory augmentation within groups who shared a memory. The indirect proxies can protect the privacy of the captured users while jogging the memories of only the people involved in the incident. (*Derived from Appendix A insight(s): Meta observation from several studies*)

11.4 Selection of Presented Cues

10. Keep Only Salient Common Details for Memory Implantation Use visualizations that hide most of the details but leave salient ones common with other memories for memory implantation. Salient details in this context refer to identifying prominent details of individuals / objects, not to the standard salient features in the domain of computer vision. Thus, the features are contextual to the memory alteration scenario. An example is blurring the people in a photo but keeping the contour of their bodies instead of using a generic rectangle-like blur filter. Assume there are two friends in a group; both are 160-cm with similar curly hair. A designer can use the contour of one to perform a memory reformation that the other was present in an event. Such techniques are also aesthetically likable by the users. Similarly, designers should be mindful of such effect as an accidental byproduct of privacy-protection methods performed on collected memory cues. (*Derived from Appendix A insight(s): 4 and 5*)

11. Maintain the Body Contour for Privacy Protection in MACS Visualizations maintaining the outer body form are preferable for protecting privacy in MACS. They provide a good trade off between removing sensitive details, preserving the photo aesthetics, and maintaining some of the salient identification features of the person. However, they provide reasonable doubt about the identity of the masked person if they want to deny their presence in a sensitive context. Additionally, they mask most of the identifying details rendering users more prone to memory implantations via misattribution and sustainability. (*Derived from Appendix A insight(s): 28,29,30,31*)

12. Reduce Details in Parallel Reviewing Reducing the presentation size of a single cue is crucial in parallel reviewing to avoid overloading the user. We recommend designers identify early on in their systems the sweet spot that masks most of the details while highlighting the salient features. An example is in the "Life-Dome" prototype: we selected the thumbnail sizes such that participants could easily see the number of people in a photo and use color similarity for quick mental parsing of events. Additionally, smaller grouping units like pages help users in building a mental model of the data to reach meta conclusions such as time spent on a task. (*Derived from Appendix A insight(s): 100 and 101*)

13. Show Minimal Cues in Ambient Augmentation MACS As we discussed in other guidelines, it is already a challenging task to achieve memory augmentation in real scenarios even when the users are completely focused on the content. Thus, this guideline is important to: (1) avoid having disruptive content on ambient systems, and (2) have reasonable content repetitions to reach an implicit augmentation state. Thus, we recommend simple representations with highly salient cues such as one photo and a line of text describing a meta finding. (*Derived from Appendix A insight(s): 92 and 98*)

11.5 Depiction of Memory Cues

14. Use Abstract Depictions to Present Indirect Memory-Sensing We recommend system designers to use abstract depictions for representing indirect signals indicating a user is recalling or reminiscing about a memory. An example is using physiological sensing to detect the user's excitement while reviewing photos in memory-augmentation MACS. Designers should avoid assigning clear labels to mental and emotional states in shared recollection scenarios as incorrect sensing can cause conflicts. For example, consider a memory-augmentation system showing the wedding photos of a couple and their families. If the users wear a tracker for heart rate to sense "excitement" and the sensing fails and the system explicitly reports that someone is "bored", the fault label can cause discord as users have tendencies to trust the systems. (*Derived from Appendix A insight(s): 16,52,53,67*)

15. Use Visual and Audio Depictions to Present Indirect Memory-Sensing Olfactory and gustatory representations are confusing in scenarios of temporal status change. For example, they should not be used to present changes in excitement when presented consecutive memory cues. The standard mapping to change by varying the intensity is not easily interpreted by users.

However, somatosensoric representations are promising. Olfactory depictions are best suited for prominent alarms like nudging users to do a meta action. An example is a system that releases a scent when the user is busy reminiscing about an event as an indication for other users to leave the person undisturbed. (*Derived from Appendix A insight(s): 55,56,68,69*)

16. Show Altered Cues Covering Longer Periods to Increase Confidence in Ambient Reformations We recommend designers to prepare memory cues covering the largest span of time possible across an event with consistent alterations in the cues. An example scenario is there are two people with similar physique and we want to convince a user that person A attended a party and not person B. We recommend showing blurred photos from different times throughout the four-hour party rather than showing photos only from the first thirty minutes. This is beneficial for systems using memory reformation strategies, particularly implantation. The rationale is the increase in the amount of presented consistent information increases the confidence of the users in the skewed recall. This effect is magnified when coupled with the users' trust in the system quality and that it cannot be mistaken. For example, we saw this effect when participants did not recognize photos present on their cameras before they joined the studies because they were sure the cameras had been cleared and all the data there must be theirs. This, for example, conforms with prior work that users do not realize the content stored on their cloud services [51]. On the other hand, missing cues decrease the user's confidence in the recalled content and allows them to have the benefit of the doubt that they are forgetting something. Designers can use this effect for the purpose of memory attenuation. The combination of both effects should be used wisely to avoid accidentally triggering them through curation choices of cues in memory-augmentation MACS. For example, consider a reviewing system that systematically coincidentally includes photos of person A in the same birthday party. Such a system with enough repetitions can cause memory reformations of the user's perception of the party attendees. (*Derived from Appendix A insight(s): 24,25,34,58,59,93,94*)

17. Procedural Cues Give a Sense of Familiarity while Entertaining Cues Give a Sense of Belonging This guideline is valid in ambient memory augmentation scenarios to bond users with a place. We encourage designers to design cues focused on crude information about basic procedures for newcomers to support their sense of familiarity and control of their surroundings. However, cues directed at more seasoned users of a place should focus on entertainment to support their sense of belonging. As an example, assume a university wants to design content for a large display encouraging students to join the music ensemble. An effective visualization for newcomers could show the location of the rehearsal

room, the provided instruments and the training time. On the other hand, an effective one to attract regular students could show backstage videos of rehearsals with some fun activities. (*Derived from Appendix A insight(s): 74,75,76*)

11.6 Storage of Captured Cues

18. Storage of (Near-)Continuous Data Remains Challenging Users are still apprehensive about investing in-storage solutions from near-continuous capturing devices. The captured data has a massive digital footprint. Current MACS do not offer immediate value to users to justify the storage costs. An example is that one-month data of pictorial lifelogs captured every 30 seconds consumes approximately 30 Gigabytes[28]. Thus, system designers are encouraged to invest in compressing the data, particularly in memory augmentation systems, capitalizing on storing as much as possible. (*Derived from Appendix A insight(s): 22,23,35,36,43,44*)

19. Store (Near)-Continuous Rich Cues Locally in Studies Researchers are highly encouraged to store rich cues such as photos, audio, and video only locally on a device accessible only by the participant during studies. This design decision highly impacted the recruitment in our studies. Participants were particularly apprehensive of less commercial technologies such as lifelogging cameras as they did not know what to expect and imagined the captured content to be mostly sensitive. Thus, they often discussed the security and accessibility of the data during recruitment and debriefing meetings. (*Derived from Appendix A insight(s): 42*)

11.7 Summary

In this chapter, we presented nineteen design guidelines for building MACS. The design guidelines are a consolidation of the insights collected throughout this thesis from the eight research projects we presented earlier. We grouped the guidelines into six groups and summarized them below in Table 11.2.

[28] Average calculation from our longitudinal study.

Table 11.1: Summary of the MemAlt parameters we learnt about through each of the research projects. (Ac) stands for active, (Am) stands for ambient, (AG) stands for memory augmentation, and (RE) stands for memory reformation.

MemAlt Pipeline Parameter	*AcAG*		*AcRE*	*AmAG*	*AmRE*
	RDT	Life Rewinder	Spotless Mind	Campus Buddy	PPM Cloaker
1. Censorship	■	■			■
2. Trigger	■				
3. Continuity	■				
4. Perspective	■				■
5. Proxy	■		■	■	■
6. Abstraction	■		■		■
7. Format preservation		■	■		■
8. Security	■				
9. Deletion governance	■				■
10. Personal authorization	■				■
11. Access rights	■		■	■	
12. Location	■				
13. Backup					
14. Syncing	■		■		
15. Inheritance	▨	▨	▨	▨	▨
16. Format preservation	■		■	■	■
17. Abstraction	■	■	■	■	■
18. Scope	■	■	■		
19. Curation	■	■		■	
20. Materiality	■		■	■	
21. Persistence			■	■	
22. System trigger				■	
23. Access rights		■		■	
24. Required attention		■		■	■
25. Integration		■		■	
26. Density	■		■		■

Table 11.2: Summary of design guidelines for building MACS.

Use Cases for MACS
1. Daily Reviews are Not Enough for Memory Augmentation
2. Design Augmentation MACS for Progressive Events and Imparting Knowledge
3. Use Parallel Reviewing for Reflection and Imparting Knowledge
4. Show Pictorial Lifelogs Samples in Debriefings
Capturing Setup
5. Design Inclusive Cameras and Capturing Devices
6. Enable Capturing Governance for Known Bystanders
7. Third-Person Captures are Richer but First-Person are More Natural
Proxy of Captured Cues
8. Use Direct Proxies for Informational Ambient Alteration
9. Use Indirect Proxies for Privacy Protection of Shared Memories
Selection of Presented Cues
10. Keep Only Salient Common Details for Memory Implantation
11. Maintain the Body Contour for Privacy Protection in MACS
12. Reduce Details in Parallel Reviewing
13. Show Minimal Cues in Ambient Augmentation MACS
Depiction of Memory Cues
14. Use Abstract Depictions to Present Indirect Memory-Sensing
15. Use Visual and Audio Depictions to Present Indirect Memory Sensing
16. Show Altered Cues Covering Longer Periods to Increase Confidence in Ambient Reformations
17. Procedural Cues Give a Sense of Familiarity while Entertaining Cues Gives a Sense of Belonging
Storage of Captured Cues
18. Storage of (Near-)Continuous Data Remains Challenging
19. Store (Near)-Continuous Rich Cues Locally in Studies

Chapter 12

Conclusion and Future Work

Parts of this chapter are based on the following publication(s):

P. Elagroudy and A. Schmidt. Yoda's in my head: Designing smart digital companions for social reflection. In *Adjunct Proc. CHI Workshop on Grand Challenge on Personal Informatics and AI*, 2022

Memories and remembering past events is a crucial process for human progression as it shapes our view of the world. However, in the age of informational overload and the prevalence of ubiquitous technologies, the capacity of people to remember is changing. On one hand, visions of super humans who keep track of everything are becoming technically feasible to prototype. On the other hand, there are several technical challenges to create relevant applications for the users and ethical paradoxes about interfering with a central process like remembering. The aim of this thesis is *two-fold*: (1) explore how we can amplify the human cognition by altering memories using ubiquitous-computing systems and (2) raising awareness about the accidental detrimental impact of technology on our memory. We achieve this goal by answering *five* research questions:

RQ1 What are the parameters for designing MACS?

RQ2 How to conduct privacy-aware memory research using MACS?

RQ3 How to design active MACS?

RQ4 How to design ambient MACS?

RQ5 How do users expect their shared memories to be used on MACS?

In our work, we focus on two memory alterations: augmentation and reformation (including attenuation and implantation). We answer the research questions through eight qualitative and descriptive research projects to experiment with designing MACS. We divide MACS in to two categories: (1) active MACS owned by the users with the primary goal of memory alteration, and (2) ambient MACS where the alteration is a secondary goal that users are not aware of. Five research projects allowed us to explore four use cases for memory alterations: active augmentation (**RDT** and **LifeRewinder** projects), active reformation (**SpotlessMind** project), ambient augmentation (**CampusBuddy** project), and ambient reformation (**PPMCloak** project). Our projects are centered around designing for altering episodic memory. Two research projects focused on the user expectations of utilizing their shared memories on social media as an example of widely-spread MACS (and **PandoraBox** projects). One project focused on advancing methods for memory research through in-the-wild gamification (**PrisonerOfWords** project).

12.1 Research Questions: Designing MACS

In the following sections, we summarize our answers to the research questions.

12.1.1 RQ1: Parameters for Designing MACS

This question is answered in Chapter 3. We present a technical framework for designing MACS. This is the cornerstone contribution of this thesis. The framework can be used as a design tool to guide the design process of new MACS. It could be used to design active or ambient MACS, or alternatively, as a reflection tool to compare several MACS and consolidate design findings. The framework is distilled from meta analysis of prior work and design insights from the eight research projects. The framework has three components:

1. **Memory strategy** This refers to the memory alteration technique used by the MACS. We discuss three strategies: augmentation, attenuation, and implantation. Memory augmentation refers to enhancing recall, or externalizing memories in memory prosthetic or facilitating imparting knowledge. Memory attenuation refers to forgetting details about existing memories. Memory implantation refers to remembering unfounded or misattributed fake details about an incident. Memory augmentation MACS are more prominent in current HCI literature. However, memory-reforming MACS are under-explored and present an open research opportunity.

2. ***MemAlt* pipeline** This is a technical pipeline to systematically collect and present memory cues in MACS. It is composed of four layers: (1) infrastructure layer targeting processing and privacy features, (2) capture layer focusing on collecting memory cues, (3) storage layer focusing on data warehouses for the captured cues, and (4) presentation layer focusing on selecting and showing the memory cues to induce the memory alteration. The pipeline is composed of twenty-six parameters summarized in Figure 3.1. We successfully showcased the usage of the pipeline as a design tool and reflection tool in the use cases research projects. Additionally, we used it as a reflection tool to consolidate the design findings of this thesis (see Appendix A).

3. **Media selection** This part complements the *MemAlt* pipeline and focuses on systematically selecting the media type of the captured, stored and presented memory cues. We also present eight parameters to compare various and compare common types such as photos and audio using the aforementioned parameters. The parameters are summarized in Figure 3.4.

12.1.2 RQ2: Conducting Privacy-Aware Research

This question is answered in Chapter 5. We answer this question in three parts: (1) describing methods for collecting and analyzing data to show memory alterations in a privacy-aware manner, (2) describing a method for taking laboratory memory experiments into the wild, and (3) reflecting on our experience as researchers in recruiting and debriefing participants in experiments using MACS.

Collection and Analysis Methods We contribute by extending three methods for investigating memory alterations. The methods capitalize on using MACS to conduct classical memory research in a privacy-preserving manner. Complementarily, they offer a methodological framework for investigating the impact

of using MACS on the remembering quality of the users. The methods are described in details in Section 5.2. We showcased the methods in two use cases: active memory augmentation (**RDT** project) and ambient memory reformation (**PPMCloak** project). We provide below a recap:

1. **Concealed Memory Collection (CMC)** The method is centered around collecting free recall events followed by predefined event details such as location and time. The events are short and numerous and their granularity is left to the definition of the user. The event collection phase is a standard in Psychology research. Additionally, we collected ubiquitous-validation data matching the details such as GPS location and near-continuous lifelogging photos. All the collected data is not accessible to the researchers. The event recall phase is short and time-bound while the evidence collection is extended over longer periods of time.

2. **Automated Memory Validation (AMV)** The method uses the evidence data and the recalled events from CMC to algorithmically validate the recall quality. We ask participants to select a photo out of their lifelogs that best represents the recalled event. The metadata of the photo such as capture time and location is used as a ground truth for validating the recalled details. Additionally, the selection process of the photo could be used as an external stimulus to jog the memory of the users to provide further details about the event on demand. One other possibility is measuring the confidence of the participants about recalled details before and after the stimulus. Correctness scores are logged and seen by the researchers. Additionally, researchers are allowed to log unrecognizable details such as timestamps of the photos (events). The method is best suited for investigating the impact of using MACS in real-world scenarios. This is because it prioritizes the protection of the user's privacy while recalling sensitive information instead of relying on controlled laboratory stimuli. However, it has limitations as it is challenging to validate complex details using it. It also requires careful definition of the correctness metrics to avoid false negatives in recall.

3. **Recall Correctness Score (RCS)** The method is composed of a set of recall and recognition questions about a particular event experienced by the participant and designed by the researcher. The questions are open-ended to avoid cuing the participants, should be short and have a clear answer. Two researchers afterwards label the answers with one of three labels: correct (when the answer is completely matching the ground truth), incorrect (when the answer is different than the ground truth), and semi-correct (when the answer is not accurate but has correct elements). An

example of a semi-correct answer is a question asking about the name of a person and an answer describing the physique of the correct person but failing to recall the name. Afterwards, a score is calculated for the participant by weighing the labels. The weights could be customized based on the use case. However, our standard is the the following: 2 for correct answers, 1 for semi correct answers, and 0 for incorrect answers.

Transforming Laboratory Experiments We contribute by providing a set of guidelines to transforming laboratory experiments to in-the-wild mobile games. Our contribution is relevant because it sheds the light on the trade-off between using standard gamification elements and disrupting the validity of the experimental data in the particular domain of memory research. We distill the guidelines through replicating a snippet of Ward et al.'s experiment [263] through a mobile game. The experiment investigates the impact of a length size on the quality of recall. The results from our two-week deployment with 44 participants already conform with the the original longer laboratory experiment. It shows that participants tend to recall shorter lists in forward order and longer lists in backward order. We mainly learnt that merits and input systems should be designed carefully in order not to jeopardize the experimental data by cuing the participants or over-incentivizing them. The full guidelines are shown in Section 5.2.4.

Challenges of Recruitment and Debriefing We focus in this part on the challenges of running studies involving (near-)continuous pictorial lifelogs because of their novelty for laymen users. The interaction and positioning challenges of the chest-mounted cameras are one of the factors that dishearten participants from joining lifelogging studies. However, running lifelogging studies for longer than a week is recommended to overcome novelty effect and dropouts because of confidential routines. Complementarily, explicit discussion of the participant's job tasks with the researcher is needed to underpin potential confidentiality breaches. Meanwhile, building specific use cases for pictorial lifelogs and investigating the design aspects of wearable cameras to provide a pleasurable experience remain as open realm for lifelogging research. We specifically reflect on two problems:

1. **Informed Consent about Capturing Range** Participants who have not used lifelogging devices cannot imagine the captured content. Thus, this poses a challenge in relying on their judgment to join the studies without committing privacy breaches. For example, we explained in **RDT** project that the camera captures everything in front of the participants. However, we had several participants panicking and dropping out of the study in the

first two days because they were capturing sensitive work material such as administrative passwords and tax reports. Thus, we recommend researchers to explicitly ask participants to acquire consent of their direct bosses during the course of studies. Additionally, there should be an initial testing period for using the camera only without starting the study for participants to familiarize themselves with the capturing expectations.

2. **Filtration of Donated Datasets** Participants tend to lose momentum after joining lifelogging experiments for more than a week. At a rate of ca. 1200 photos per day, participants are bound to capture sensitive information accidentally despite their best efforts. Therefore, researchers usually ask participants to review their datasets before donating them to the research project. Participants tended to skip a thorough review and trust us with the data. Although the approach protects the researcher legally, it raises ethical questions about the responsibility of data privacy breaches. An example is capturing romantic partners in sensitive situations and exposing them to the researcher although they are officially not a part of the study. In another incident, a participant donated a 65-thousand photo dataset to us knowing it had captures of their banking details, and asked us to be "careful about it". Although we asked the participant to review and delete those photos, they mentioned that it was "tedious and it is less likely that we care about this data anyways". Approaches like anonymizing the datasets to remove all screens for example highly jeopardizes the objective of having those datasets in the first place and renders them useless for further analysis. Thus, we encourage researchers to carefully interact with released datasets, limit their accessibility within the research team, and not rely on participants' filtration of sensitive information.

12.1.3 RQ3: Designing Active MACS

This question is answered by reflecting on three research projects: **RDT** and **LifeRewinder** projects targeting active memory augmentation (see Chapter 6) while **SpotlessMind** project focuses on active memory reformation (see Chapter 7). Our contribution of design recommendations comes at three levels of abstraction. First, we present concrete technical insights from each use case mapped to the *MemAlt* pipeline in Sections 6.3 and 7.6). Afterwards, we provide abstract guidelines for designing MACS in Chapter 11. Last, we provide below a consolidated outlook of all the insights.

In this question, we particularly reflect on near-continuous capturing MACS as they still offer rich research opportunities and have not became niche applications yet. We learnt that current capture devices such as chest-mounted cameras and BCI caps are not designed inclusively to be comfortable for various body types and clothing styles. For example, hair, large busts, and open neck shirts often occlude or misdirect cameras and interfere with the BCI electrodes. From our studies, female participants were more likely to negatively perceive the design compared to male participants as the designs were less tailored towards their needs. This challenge is detrimental to the acceptability of the technology with the users as they feel the urge to alter their life style to start using it. Coupled with the massive storage requirements without current clear benefits of lifelogging to the masses, users do not feel the urge to invest in lifelogging to create a comprehensive external memory prosthetic.

As users are often not aware of their capturing ranges, they will capture sensitive information about others despite their best efforts to avoid it. Thus, we learnt that it is essential to design efficient capturing governance techniques to allow "known bystanders" to have the right to be forgotten. Known bystanders are unique stakeholders that are often neglected in the design process. They are individuals who are within the capturing range, are not strangers to the user so they care if they are captured in sensitive situations, but are not the regular co-participants like the partner and office mates who are usually involved early on in the user's decision to wear a logging device. An example of known bystanders is friends who meet every week. We specifically reflect on pictorial lifelogging as it can highly expose bystanders while protecting the privacy of the users themselves. Users are bound to forget about wearing the camera and capture sensitive information because it is designed for that purpose to be forgotten and in the background. Additionally, known bystanders who do not approve of being recorded feel the social pressure to not disrupt the recording process. However, this creates discord and tension with the users and resentment towards the technology. Thus, we propose changing the designers' perspective towards the capturing devices from being forgotten and ubiquitous to treating them as "social entities" that reveal their presence to new bystanders.

We learnt that generic short daily reviews were not sufficient to see positive results of memory augmentation despite the novelty effect of the systems. Thus, we recommend researchers to explore if building ambient systems that show such memory cues more often create the required impact of intrinsic memory augmentation. Users were more inclined towards using active augmentation MACS in domain-specific cases rather than generically as we had initially aimed. For example, they often proposed across the projects the need for a system that

reviews serial events like longitudinal meetings of a project, answering questions about the mental perception of a partner towards a specific topic, or imparting knowledge by summarizing the experience of others in domains like cooking and lecturing. We learnt that parallel reviewing is better suited for reflection and imparting knowledge as it provides a holistic overview of the collected data, while sequential reviewing is better suited for an overview of daily events. Minimizing details of the presented cues to only highlight salient features was key to successfully designing parallel reviewing visualizations.

Regarding designing MACS for active memory reformation, we learnt that first-person captures of the data more naturally mimic the user's perception of the events. However, they do not capture the user and often have narrower capturing range compared to third-person captures. An example of first-person captures is the dataset from a chest-mounted camera compared to a third-person capture from a camera mounted on the walls of a meeting room. Thus, we postulate that users are more susceptible to memory reformations with first-person captures. Similarly, indirect memory proxies offer an interesting design opportunity for cuing shared memories within groups while preserving the privacy of the users involved. Indirect proxies are cues that do not capture an incident but a generic element that relates to it, such as capturing a cake photo as a proxy for a birthday party celebration. They offer good trade-off for having a memory cue about an incident to support memory augmentation. Nevertheless, it is hard to interpret it without knowing the context of the incident. However, we also postulate that users are more prone to memory reformations due to misattribution and suggestibility when indirect proxies are used. They are also less sustainable and interpretable over time as the context of the incident itself decays. An example is a user seeing a photo of a birthday ten years after the party and not being sure whether it was the cake from their party or their friend's party. We also recommend using abstract depictions (particularly visual and audio ones) to present information regarding indirect sensing of a user's ability to recall an incident. For example, it is not appropriate to conclusively assign in an application a label to the user's state such as "user forgot about the incident" if it is being evaluated via physiological sensing. Concrete labels increase the apprehension of the users towards systems as they fear potential discord from inaccurate sensing.

12.1.4 RQ4: Designing Ambient MACS

This question is answered by reflecting on two research projects: the **Campus-Buddy** project targeting ambient memory augmentation (see Chapter 8) and

the **PPMCloak** project targeting ambient memory reformation (see Chapter 9). Similar to **RQ3**, our contribution of design guidelines also comes at three levels of abstraction. The technical guidelines per use case are summarized in Sections 8.5 and 9.3 respectively. Afterwards, we present abstract guidelines in Chapter 11. Lastly, we present a consolidated outlook in this section.

The design of ambient MACS raises critical ethical concerns about the intentional alteration of the users' memories without their explicit consent. However, this is already widespread in niche applications. Example domains include designing memorable advertisements and knowledge imparting applications such as language learning tools and lectures about technical topics. In some other cases, it is only an accidental by-product to other design decisions that is not explicitly accounted for while building systems. Thus, in this section, we highlight design patterns that we think contribute to the ambient alteration. However, the design patterns are presented with a neutral stance without endorsing their incorporation in systems or frowning upon their usage, as the ethics involved highly depends on the system's context. We focus our recommendations around visual systems to match the nature of our experimental projects.

We learnt that direct proxies capturing incidents directly are better suited for ambiently altering memories when it comes to procedures and crude information. An example is having an e-frame continuously displaying parts of a lecture to augment the intrinsic memory of a student about the academic content. This is preferable to displaying indirect proxies such as notes or photos of the lecture's attendees. The reason is as we saw from **RQ3**, achieving memory augmentation in real-world scenarios is already challenging in case of active systems where the user is cooperative and attentive to the content. Thus, we postulate that it is crucial to minimize the presented cues in ambient displays and prioritize displaying them frequently to achieve alterations and avoid disrupting users. We learnt that procedural cues focusing on basic information gives a sense of familiarity about a new location while entertaining cues give a sense of belonging. An example of procedural cues is information on a bulletin like timings of meetings and important locations in a building. An example for entertaining cues is engaging content focusing on music, sports and games.

As opposed to the recommended cues' density reduction in the memory augmentation context, we learnt that increasing the cues' density is better suited to the context of memory reformation. Distorting most of the details allows salient details responsible for misattribution and suggestability to be highlighted. An example is having numerous photos having the same blurred person Tom, who looks similar to another one, Daniel, is more likely to make a user believe Daniel

is in the photos as opposed to only showing a couple of blurred photos. The reason is that users' confidence in the recalled details is directly proportional to the increase in the amount of presented evidence, that is the number of photos in this case. our **PPMCloak** project showed that users remember more details with high confidence but low accuracy using blurred photos covering the full dataset. This means that blurring is good to remember more about a forgotten topic but not to recall accurate details of memories. Thus, we also recommend maintaining the body contour of users in photos. This provides a good trade-off between protecting their privacy while maintaining palatable aesthetics of the final photos. It preserves most of the details in the photo rendering it useful as a memory cue for memory augmentation. However, the blurring of people provides required doubt about the identity of the people in a cue. On one hand, this could be used by privacy-aware users to deny their presence in a sensitive context. On the other, it leaves other users more prone to accidental or intentional memory reformations using such altered cues.

12.1.5 RQ5: Utilization of Shared Memories

This question is answered by mainly reflecting on two research projects in the context of social media, namely **E-Ally** and **PandoraBox** projects covered in Chapter 10. We chose Facebook as an example of widely-used media. Both projects demonstrate the use case of users sharing their memories and other sensitive information about their behavior on MACS and clarify their expectations of how other users interact with their memories as well as how systems analyse the memories to build smart interactions. Both projects are considered ambient alteration scenarios as users are not intentionally seeking any of the memory alterations and are surprised about them taking place. Additionally, we reflect on some of the qualitative data in **RDT** and **SpotlessMind** to reflect on sharing practices in active MACS. Challenges and design guidelines are highlighted in Section 10.3 and Section 7.4.3. We answer the question from two angles: (1) user expectations towards other users sharing the memory beyond the intended context, and (2) user expectations towards systems meta analysing memories and using the insights to create smart interactions.

Expectations towards Other Users We learnt that users do not realistically estimate the reachability of their shared content and the potential misuse of it. We observed this in the context of social media in support groups (**E-Ally** project). They translate models of trusting friends in offline interactions into the virtual support groups with strangers. We observed a similar pattern in the context of

the **SpotlessMind** project. Users mostly did not define their relationship with observers (people watching the exhibition) as sharing even though those observers could perceive all the content just like the other sharer. Similarly, they were as accepting of sharing with their colleagues as sharing with total strangers. In both projects, users shared their content to prove closeness with others even if they were strangers. The pattern was also repeated in **RDT** project, where users were accepting of sharing highly sensitive content such as passwords and tax information via their lifelogs with the researchers because they did not think we would benefit from misusing it. This phenomenon has severe social consequences for vulnerable user groups. For example, in the context of the **E-Ally** project, users were exposed to defamation and divorce because of other users sharing their content beyond the scope of the virtual support group. In the **SpotlessMind** project, users were concerned about "bullies" using their shared content against them by identifying their current mental state and provoking them. Thus, there is an open research opportunity for HCI researchers to develop safer interactions that are privacy-aware to enable such communities. To achieve this, we need to further understand the mental metaphors used by users to decide on sharing or refraining from sharing of memories. One suggestion is to develop techniques that highlight who can see a particular memory from current connections.

Expectations towards Smart Systems We identified four types of personalized interactions that users find surprising on smart platforms: customized advertisements, cuing offline interactions, sharing data with third-party applications and cued curation of news feed. An example for cuing offline interactions is suggesting a connection with a person you may know after being in the same geographical location. An example for cued curation of news feed is suddenly showing more content of a particular connection the user does not often interact with. We learnt that users are apprehensive of personalized content resulting from sharing and analyzing their data when they believe it generates revenue for the platform. Additionally, there is a mismatch in defining the priorities of personalization features between commercial platforms and the users. For example, cuing offline interactions with people was negatively perceived though recognized by the users. There was a trend that female users noticed offline cuing incidents more than male users. Male users on the other hand focused their reports on data sharing incidents. Customized advertisements were frequently reported by older participants. However, the users' negative perception of a platform does not necessarily translate to changes in their usage patterns.

12.2 Future of MACS

We envision a future where domain-specific MACS are ubiquitously embedded in the user's daily interactions. In this section, we propose research directions to further build upon the work done in this thesis. They are centered around amplifying the user's capability to reflect on their behavior and alter their attitude. We specifically believe in this goal as memories are among the primary constructs shaping our reactions towards the world. However, the natural memory "sins" could potentially misguide our attitude towards other people and experiences. Thus, we envision smart systems that enable people to gain better control and objective outlook of their past as well as help them in learning and imparting knowledge faster. We envision the presence of smart MACS that particularly support increasing the user's social intelligence. We discuss below six research directions with various abstraction levels:

Supporting Emotional Fairness Via Reflection This research direction aims to overcome skewed interactions in relationships resulting from the bias and transience of past memories. We specifically recommend looking for ways to encourage users to have emotional fairness in judging the quality of a relationship during emotionally-charged events. For example, consider the tendency of a person to remember past conflicts with a partner during an ongoing fight and thinking that a relationship is mostly filled with negative moments. Such behavior increases the aggravation towards the partner and can lead to stronger negative reactions towards the ongoing conflict. We envision a system that can help users restore a balanced view of their relationship. One possible way worth investigating is presenting past memory cues from events offering the inverse affect of the situation at hand. For example, in the previous scenario, the system would show photos from happy events during times of conflict.

Ambient Cuing for Supporting Communication This research direction aims to support users in fulfilling their social obligations and enhancing their social interactions via subtly cuing them to overcome absentmindedness. We specifically recommend investigating two scenarios: (1) cuing to encourage communication with family and friends, and (2) cuing to encourage communication with partners. In the first scenario, we envision using memory cues from past shared experiences within a group of people to encourage users to contact the other members of the group at specific times. The times would be automatically assigned by the smart system based on knowledge we have from social sciences about optimal communication intervals to maintain healthy relationships. We envision using nontraditional multi-sensory cues for the subtle cuing. For example,

one idea for the cues is using the scent of common foods consumed within the group. For example, consider the system releasing the scent of cookies and the user remembering the Christmas times at their grandparents' place where they ate cookies, so they go and call them. In the second scenario, we envision using cues from past memories as reminders to provide positive reinforcement for the users to do actions that make the partner happy but they usually forget about. An example is reminding the user one month before their partner's birthday using photos from last year's birthday of how happy their partner was with their gift, and proposing a set of gifts extracted from the conversations of the partners.

Ambient Reformations in Privacy-Aware Systems We know from prior work discussed in Section 2.4 that photos are commonly used as triggers for memory reformation, particularly implantation. This research direction aims to further understand and raise awareness about the accidental memory reformations resulting from using privacy protection methods with digital artifacts. It particularly focuses on the potential hazards of suggestability and misattribution from the altered artifacts. The work done in this thesis scratched the surface of this problem (e.g. see **PPMCloak** project). However, further research is required to systematically investigate the impact of the plethora of industry and research standards in privacy on the quality of recall and recognition of memories. The work could also be extended to look at the impact of general extended usage of technological interventions such as social media on the human memory.

Amplified Cognition via Parallel Reviewing This research direction is inspired by our work in the "Life-Dome" prototype. We envision the development of a visualization toolkit to present numerous memory cues for parallel reviewing. The objective of the toolkit is to capitalize on the human capabilities of recognizing patterns and reaching meta conclusions from large datasets. We envision having the tool kit use multimodal representations for cues with clear recommendations on use cases for each visualization. The tool kit would be mainly designed for the purpose of reflection and imparting knowledge. Thus, users should be able to quickly at a glance understand meta patterns about their behavior. Additionally, they should be able to quickly grasp the steps of a skill if they see the dataset of another person.

Smart Lifelogging for Psychiatric Treatment This is a broader research direction that requires joining the forces in interdisciplinary teams. The current body of research shows potential for using memory augmentation to objectively alter skewed perception of patients and for using memory reformations in cognitive behavior therapy. For example, Qu et al. [207] looked at using lifelogging technologies to overcome impairments in autobiographical memories in depression patients causing negative perception of surroundings to effectively alleviate

the symptoms . At the same time, we discussed earlier in Section 2.4.2 several scenarios where memory reformation can help PTSD patients. We envision continuing these lines of work and using lifelogging technologies as an aiding tool for psychiatrists in their course of treatment. We propose using pictorial and audio near-continuous lifelogs in three scenarios within cognitive behavioral therapy and to understand the patients' triggers. The first scenario is using lifelogs as an objective record to help paranoia and anxiety patients reflect on their skewed thoughts and emotions. The second is selective lifelogging in opportune moments based on physiological sensing to help anxiety and panic attack patients reflect on their triggers. The third is using altered lifelogs to reform the memories of PTSD patients. We envision helping patients by designing personalized intelligent MACS.

Physiological Sensing for Memories This research direction is better suited as a long-term vision for MACS. We envision the development of physiological sensing techniques to view and reconstruct memories. We also envision the ability to store and access memories and other digital information in a biological cells of the body. This offers a trade-off between having an "external memory prosthetic" and having portable accessibility of data without storage limitations. This vision is not far fetched as we currently have solutions enabling storage and retrieval from DNA format inside micro-organisms or only as proteins [35, 6]. Examples include storing passwords in DNA format in a biological form inside the person's freezer [2], reconstruction of GIFs from DNA [233], storing data in neurons [9], and storing data in carbohydrates. The technology is still in its infancy, offering rich research opportunities for development. However, the long information access times (ranging in tens of hours [35]) because of the need to decode the entire data stored will make them better archival purposes rather than real time interactions. Nevertheless, it offers the potential indefinite archival space for as long as centuries [35].

In a world where MACS prevail, we envision systems that promote emotional intelligence and mental well-being of individuals. Such systems are available as part of our daily interactions either externally, like mobile phones, or internally through cellular storage. They enable people to learn and reflect on their experiences critically, enabling them to become better versions of themselves and accentuating the human experience.

Bibliography

BIBLIOGRAPHY

[1] 40 mandela effect examples that will blow your mind. https://www.goodhousekeeping.com/life/entertainment/g28438966/mandela-effect-examples/. Last accessed: 2021-07-13.

[2] Bitcoin fanatics are storing their cryptocurrency passwords in dna. https://www.cnet.com/news/bitcoin-fanatics-are-storing-their-cryptocurrency-passwords-in-dna-carverr/. Last accessed: 2021-08-01.

[3] Cathal gurrin - research interests. https://www.dcu.ie/researchsupport/research-profile?PERSON_ID=1637780#tab-research. Last accessed: 2021-07-13.

[4] Colour of life wall at lifelogging. https://www.youtube.com/watch?v=AVHay0jTS9M&ab_channel=ScienceGalleryDublin. Last accessed: 2021-07-14.

[5] Crowdsourcing with mobile apps brings big data to psychological research. https://www.pharmacytimes.com/news/crowdsourcing-with-mobile-apps-brings-big-data-to-psychological-research. Last accessed: 2021-01-11.

[6] Dna data storage alliance. https://dnastoragealliance.org/. Last accessed: 2021-08-01.

[7] Dr. sarah clinch. https://www.research.manchester.ac.uk/portal/en/researchers/sarah-clinch(3b771f1a-0017-435c-9ec2-39183ec4371d).html. Last accessed: 2021-07-13.

[8] Forgetit - concise preservation by combining managed forgetting and contextualized remembering. https://www.dfki.

de/web/forschung/projekte-publikationen/projekte-uebersicht/projekt/forgetit/. Last accessed: 2021-07-13.

[9] Koniku bio is life. https://koniku.com/technology. Last accessed: 2021-08-01.

[10] Materialising memories: Design research to support remembering practices. https://www.materialisingmemories.com/. Last accessed: 2022-07-25.

[11] Mylifebits - microsoft research. https://www.microsoft.com/en-us/research/project/mylifebits/. Last accessed: 2021-07-13.

[12] Quantified self - self knowledge through numbers. https://quantifiedself.com/. Last accessed: 2021-07-13.

[13] Recall - rethinking and redefining memory augmentation. https://recall-fet.org/about/. Last accessed: 2021-07-13.

[14] Y. Abdelrahman, M. Hassib, M. G. Marquez, M. Funk, and A. Schmidt. Implicit Engagement Detection for Interactive Museums Using Brain-Computer Interfaces. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct - MobileHCI '15*, pages 838–845, New York, New York, USA, 2015. ACM Press.

[15] A. Acquisti, I. Adjerid, R. Balebako, L. Brandimarte, L. F. Cranor, S. Komanduri, P. G. Leon, N. Sadeh, F. Schaub, M. Sleeper, et al. Nudges for privacy and security: Understanding and assisting users' choices online. *ACM Computing Surveys (CSUR)*, 50(3):1–41, 2017.

[16] D. Adams, H. Paterson, and H. MacDougall. Law and (rec)order: Updating memory for criminal events with body-worn cameras. *PLoS ONE*, 15, 2020.

[17] P. Aditya, R. Sen, P. Druschel, S. Joon Oh, R. Benenson, M. Fritz, B. Schiele, B. Bhattacharjee, and T. T. Wu. I-pic: A platform for privacy-compliant image capture. In *Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services*, MobiSys '16, pages 235–248, New York, NY, USA, 2016. ACM.

[18] J. E. Agolla and H. Ongori. An assessment of academic stress among undergraduate students: The case of university of botswana. 2009.

[19] M. Ahn, M. Lee, J. Choi, and S. C. Jun. A review of brain-computer interface games and an opinion survey from researchers, developers and users. *Sensors (Basel, Switzerland)*, 14(8):14601–33, aug 2014.

[20] F. Alt, S. Schneegass, M. Girgis, and A. Schmidt. Cognitive effects of interactive public display applications. In *Proceedings of the 2nd ACM International Symposium on Pervasive Displays*, PerDis '13, page 13–18, New York, NY, USA, 2013. Association for Computing Machinery.

[21] J. Amores, X. Benavides, and P. Maes. PsychicVR. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '16*, pages 2–2, New York, New York, USA, 2016. ACM Press.

[22] C. Andrews, A. Endert, and C. North. Space to think: large high-resolution displays for sensemaking. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 55–64, 2010.

[23] M. Andujar and J. E. Gilbert. Let's learn!: enhancing user's engagement levels through passive brain-computer interfaces. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13*, page 703, New York, New York, USA, 2013. ACM Press.

[24] M. Andujar and J. E. Gilbert. A user-centered approach towards attention visualization for learning activities. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers on - UbiComp '17*, pages 871–876, New York, New York, USA, 2017. ACM Press.

[25] M. Armstrong and S. Alliance. Virtual support groups for informal caregivers of individuals with dementia. *Alzheimer Disease & Associated Disorders*, 33:362 – 369, 2019.

[26] A. Baddeley, M. W. Eysenck, and M. C. Anderson. *Memory*. Psychology Press Taylor and Francis Group, 2009.

[27] N. S. Baron. Know what? how digital technologies undermine learning and remembering. *Journal of Pragmatics*, 175:27–37, 2021.

[28] D. Barreau, A. Crystal, J. Greenberg, A. Sharma, M. Conway, J. Oberlin, M. Shoffner, and S. Seiberling. Augmenting memory for student learning:

Designing a context-aware capture system for biology education. *Proceedings of the American Society for Information Science and Technology*, 43(1):1–6, 2006.

[29] G. Bell and J. Gemmell. *Your life, uploaded: The digital way to better memory, health, and productivity*. Penguin, 2010.

[30] J. L. Bender, M.-C. Jimenez-Marroquin, and A. R. Jadad. Seeking support on facebook: a content analysis of breast cancer groups. *Journal of medical Internet research*, 13(1):e16, 2011.

[31] E. Berry, N. Kapur, L. Williams, S. Hodges, P. Watson, G. Smyth, J. Srinivasan, R. Smith, B. Wilson, and K. Wood. The use of a wearable camera, sensecam, as a pictorial diary to improve autobiographical memory in a patient with limbic encephalitis: A preliminary report. *Neuropsychological Rehabilitation*, 17(4-5):582–601, 2007. PMID: 17676536.

[32] A. Besmer and H. Lipford. Tagged photos: Concerns, perceptions, and protections. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '09, pages 4585–4590, New York, NY, USA, 2009. ACM.

[33] A. Bexheti, A. Fedosov, I. Elhart, and M. Langheinrich. Memstone: A tangible interface for controlling capture and sharing of personal memories. In *Proceedings of the 20th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '18, pages 20:1–20:13, New York, NY, USA, 2018. ACM.

[34] A. Bexheti, A. Fedosov, J. Findahl, M. Langheinrich, and E. Niforatos. Relive the moment: Visualizing run experiences to motivate future exercises. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*, MobileHCI '15, page 986–993, New York, NY, USA, 2015. Association for Computing Machinery.

[35] J. Bornholt, R. Lopez, D. Carmean, L. Ceze, G. Seelig, and K. Strauss. A dna-based archival storage system. *Proceedings of the Twenty-First International Conference on Architectural Support for Programming Languages and Operating Systems*, 2016.

[36] L. Breuer and C. Barker. Online support groups for depression. *SAGE Open*, 5, 2015.

[37] H. R. Brown, P. Zeidman, P. Smittenaar, R. A. Adams, F. McNab, R. B. Rutledge, and R. J. Dolan. Crowdsourcing for cognitive science–the utility of smartphones. *PloS one*, 9(7):e100662, 2014.

[38] F. Brunton and H. Nissenbaum. *Obfuscation: A User's Guide for Privacy and Protest*. The MIT Press, 2015.

[39] H. Buchanan and N. Coulson. Accessing dental anxiety online support groups: an exploratory qualitative study of motives and experiences. *Patient education and counseling*, 66 3:263–9, 2007.

[40] F. Buongiorno. The digital self: The construction of self and social recognition in the global digital society. In *Athens: ATINER'S Conference Paper Series*, 2016.

[41] V. Bush. As we may think. In *INTR*, 1996.

[42] D. Byrne, A. R. Doherty, C. G. Snoek, G. J. Jones, and A. F. Smeaton. Everyday concept detection in visual lifelogs: validation, relationships and trends. *Multimedia Tools and Applications*, 49(1):119–144, 2010.

[43] D. Byrne, H. Lee, G. J. Jones, and A. F. Smeaton. Guidelines for the presentation and visualisation of lifelog content. 2008.

[44] C. Cadwalladr and E. Graham-Harrison. The cambridge analytica files. *The Guardian*, 21:6–7, 2018.

[45] S. Carr, C. Stephen, M. Francis, L. G. Rivlin, and A. M. Stone. *Public space*. Cambridge University Press, 1992.

[46] Y. Chen and G. J. F. Jones. Augmenting human memory using personal lifelogs. In *Proceedings of the 1st Augmented Human International Conference*, AH '10, pages 24:1–24:9, New York, NY, USA, 2010. ACM.

[47] P.-Y. Chi, X. Xiao, K. Chung, and C. Chiu. Burn your memory away: one-time use video capture and storage device to encourage memory appreciation. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*, pages 2397–2406. 2009.

[48] E. K. Choe, N. B. Lee, B. Lee, W. Pratt, and J. A. Kientz. Understanding quantified-selfers' practices in collecting and exploring personal data. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, pages 1143–1152, New York, NY, USA, 2014. ACM.

[49] E. F. Churchill, L. Nelson, and L. Denoue. Multimedia fliers: Information sharing with digital community bulletin boards. In *Communities and technologies*, pages 97–117. Springer, 2003.

[50] M. A. Ciranni and A. P. Shimamura. Retrieval-induced forgetting in episodic memory. *Journal of experimental psychology. Learning, memory, and cognition*, 25 6:1403–14, 1999.

[51] J. W. Clark, P. Snyder, D. McCoy, and C. Kanich. *"I Saw Images I Didn't Even Know I Had": Understanding User Perceptions of Cloud Storage Privacy*, page 1641–1644. Association for Computing Machinery, New York, NY, USA, 2015.

[52] S. Clinch, J. Alexander, and S. Gehring. A survey of pervasive displays for information presentation. *IEEE Pervasive Computing*, 15(3):14–22, 2016.

[53] S. Clinch, O. Alghamdi, and M. Steeds. Technology-induced human memory degradation. In *Creative Speculation on the Negative Effects of HCI Research. Workshop at The ACM CHI Conference on Human Factors in Computing Systems (CHI 2019).*, 2019.

[54] S. Clinch, C. Cortis Mack, G. Ward, and M. Steeds. *Technology-Mediated Memory Impairment*, pages 71–124. Human–Computer Interaction Series. Springer Nature, United States, Jan. 2021.

[55] S. Clinch, N. Davies, M. Mikusz, P. Metzger, M. Langheinrich, A. Schmidt, and G. Ward. Collecting shared experiences through lifelogging: Lessons learned. *IEEE Pervasive Computing*, 15(1):58–67, Jan 2016.

[56] S. Clinch, T. Dingler, K. Kunze, P. E. Agroudy, and T. Terada. WAHM - 4th workshop on ubiquitous technologies to augment the human mind: sharing experiences. In *Adjunct Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers, UbiComp/ISWC 2017, Maui, HI, USA, September 11-15, 2017*, pages 662–665. ACM, 2017.

[57] S. Clinch, P. Metzger, and N. Davies. Lifelogging for 'observer' view memories: An infrastructure approach. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*, UbiComp '14 Adjunct, pages 1397–1404, New York, NY, USA, 2014. ACM.

[58] M. A. Conway. Episodic memories. *Neuropsychologia*, 47(11):2305–2313, 2009.

[59] F. Curmi, M. A. Ferrario, and J. Whittle. Sharing real-time biometric data across social networks: Requirements for research experiments. In *Proceedings of the 2014 Conference on Designing Interactive Systems*, DIS '14, pages 657–666, New York, NY, USA, 2014. ACM.

[60] N. S. Dalton, E. Collins, and P. Marshall. *Display Blindness? Looking Again at the Visibility of Situated Displays Using Eye-Tracking*, page 3889–3898. Association for Computing Machinery, New York, NY, USA, 2015.

[61] A.-F. E. Darwish and G. L. Huber. Individualism vs collectivism in different cultures: a cross-cultural study. *Intercultural Education*, 14(1):47–56, 2003.

[62] N. Davies, A. Friday, S. Clinch, C. Sas, M. Langheinrich, G. Ward, and A. Schmidt. Security and privacy implications of pervasive memory augmentation. *IEEE Pervasive Computing*, 14(1):44–53, 2015.

[63] T. Denning, Z. Dehlawi, and T. Kohno. In situ with bystanders of augmented reality glasses: Perspectives on recording and privacy-mediating technologies. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*, CHI '14, pages 2377–2386, New York, NY, USA, 2014. ACM.

[64] T. Dingler, P. E. Agroudy, H. V. Le, A. Schmidt, E. Niforatos, A. Bexheti, and M. Langheinrich. Multimedia memory cues for augmenting human memory. *IEEE Multim.*, 23(2):4–11, 2016.

[65] T. Dingler, P. E. Agroudy, G. Matheis, and A. Schmidt. Reading-based screenshot summaries for supporting awareness of desktop activities. In *Proceedings of the 7th Augmented Human International Conference, AH 2016, Geneva, Switzerland, February 25-27, 2016*, pages 27:1–27:5. ACM, 2016.

[66] T. Dingler, P. E. Agroudy, G. Matheis, and A. Schmidt. Reading-based screenshot summaries for supporting awareness of desktop activities. In *Proceedings of the 7th Augmented Human International Conference 2016*, AH '16, New York, NY, USA, 2016. Association for Computing Machinery.

[67] T. Dingler, P. E. Agroudy, R. Rzayev, L. Lischke, T. Machulla, and A. Schmidt. Memory augmentation through lifelogging: Opportunities and challenges. 2021.

[68] T. Dingler and N. Henze. That's the dog from my wedding – algorithms for memory shaping. Workshop Paper. Adjunct Proceedings. CHI Workshop on Designing Technology for Major Life Events, April 2014. Retrieved June 24, 2016 from `https://sites.google.com/site/techmajorlifeevents/Dinger.pdf?attredirects=0`.

[69] T. Dingler, D. Weber, M. Pielot, J. Cooper, C. Chang, and N. Henze. Language learning on-the-go: opportune moments and design of mobile microlearning sessions. In M. Jones, M. Tscheligi, Y. Rogers, and R. Murray-Smith, editors, *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI 2017, Vienna, Austria, September 4-7, 2017*, pages 28:1–28:12. ACM, 2017.

[70] A. R. Doherty, D. Byrne, A. F. Smeaton, G. J. Jones, and M. Hughes. Investigating keyframe selection methods in the novel domain of passively captured visual lifelogs. In *Proceedings of the 2008 International Conference on Content-based Image and Video Retrieval*, CIVR '08, pages 259–268, New York, NY, USA, 2008. ACM.

[71] A. R. Doherty, N. Caprani, C. Ó. Conaire, V. Kalnikaite, C. Gurrin, A. F. Smeaton, and N. E. O'Connor. Passively recognising human activities through lifelogging. *Computers in Human Behavior*, 27(5):1948–1958, 2011.

[72] A. R. Doherty, C. J. Moulin, and A. F. Smeaton. Automatically assisting human memory: A sensecam browser. *Memory*, 19(7):785–795, 2011.

[73] A. R. Doherty, K. Pauly-Takacs, N. Caprani, C. Gurrin, C. J. A. Moulin, N. E. O'Connor, and A. F. Smeaton. Experiences of aiding autobiographical memory using the sensecam. *Human–Computer Interaction*, 27(1-2):151–174, 2012.

[74] P. Elagroudy, Y. Abdelrahman, S. Faltaous, S. Schneegass, and H. Davis. Workshop on amplified and memorable food interactions. In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia, MUM 2018, Cairo, Egypt, November 25-28, 2018*, pages 551–555. ACM, 2018.

[75] P. Elagroudy, S. S. Feger, and A. Schmidt. A model for selecting media type of memory cues in ubiquitous prostheses. In *AHs 2022: Augmented Humans 2022, Hybrid Event / Munich, Germany, March 13 - 15, 2022*, pages 313–316. ACM, 2022.

[76] P. Elagroudy, M. Khamis, F. Mathis, D. Irmscher, A. Bulling, and A. Schmidt. Can privacy-aware lifelogs alter our memories? In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems, CHI 2019, Glasgow, Scotland, UK, May 04-09, 2019*. ACM, 2019.

[77] P. ElAgroudy, M. Khamis, F. Mathis, D. Irmscher, A. Bulling, and A. Schmidt. Can privacy-aware lifelogs alter our memories? In *Proceedings of the 37th Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '19, New York, NY, USA, 2019. ACM.

[78] P. ElAgroudy, P. Khoshdani, T. Dingler, G. Ward, P. W. Woźniak, and A. Schmidt. Prisoner of words: Lessons learnt from mobile gamification of lab memory experiments. In *Extended Abstracts of the 2021 Annual Symposium on Computer-Human Interaction in Play (CHI Play)*, pages 256–261, 2021.

[79] P. Elagroudy, T. Machulla, R. Rzayev, T. Dingler, M. Funk, A. Schmidt, G. Ward, and S. Clinch. Impact of reviewing lifelogging photos on recalling episodic memories. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing, UbiComp Adjunct 2016, Heidelberg, Germany, September 12-16, 2016*, pages 1014–1019. ACM, 2016.

[80] P. Elagroudy and M. Saleh. We have each others' backs: A study on women only facebook groups. In *Adjunct Proc. CHI Workshop on Sensitive Research, Practice and Design in HCI*, 2019.

[81] P. Elagroudy, M. Saleh, C. Sturm, and A. Schmidt. How do users expect their smart memory vaults to utilize their shared memories? In *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA, 29 April 2022 - 5 May 2022*, pages 448:1–448:6. ACM, 2022.

[82] P. Elagroudy and A. Schmidt. Yoda's in my head: Designing smart digital companions for social reflection. In *Adjunct Proc. CHI Workshop on Grand Challenge on Personal Informatics and AI*, 2022.

[83] P. Elagroudy, C. Soliman, S. Abdennadher, and A. Schmidt. Liferewinder: speed reviewing of lifelogs using tangibles. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays, PerDis 2019, Palermo, Italy, June 12-14, 2019*, pages 30:1–30:2. ACM, 2019.

[84] P. Elagroudy, X. Wang, E. Stemasov, T. Hirzle, S. Shishkovets, S. Mehrotra, and A. Schmidt. Spotlessmind: A design probe for eliciting attitudes towards sharing neurofeedback. In *Proceedings of the Augmented Humans International Conference, AH 2020, Kaiserslautern, Germany, 16-17 March, 2020*, pages 24:1–24:8. ACM, 2020.

[85] M. Eldridge, A. Sellen, and D. Bekerian. Memory problems at work: Their range, frequency and severity. *Rank Xerox, EuroPARC*, 1992.

[86] D. Elsweiler, I. Ruthven, and C. Jones. Towards memory supporting personal information management tools. *Journal of the American Society for Information Science and Technology*, 58(7):924–946, 2007.

[87] J. T. Enns and S. Macdonald. The role of clarity and blur in guiding visual attention in photographs. *Journal of experimental psychology. Human perception and performance*, 39 2:568–78, 2013.

[88] M. Eslami, K. Karahalios, C. Sandvig, K. Vaccaro, A. Rickman, K. Hamilton, and A. Kirlik. First i" like" it, then i hide it: Folk theories of social feeds. In *Proceedings of the 2016 cHI conference on human factors in computing systems*, pages 2371–2382, 2016.

[89] A. Felgenhauer, K. Kaufmann, J. Klier, and M. Klier. In the same boat: social support in online peer groups for career counseling. *Electronic Markets*, 31:197–213, 2021.

[90] J. R. Finley, W. F. Brewer, and A. S. Benjamin. The effects of end-of-day picture review and a sensor-based picture capture procedure on autobiographical memory using sensecam. *Memory*, 19(7):796–807, 2011.

[91] I. Flammer. Genteel wearables: Bystander-centered design. *IEEE Security Privacy*, 14(5):73–79, Sept.-Oct. 2016.

[92] J. C. Flanagan. The critical incident technique. *Psychological bulletin*, 51(4):327, 1954.

[93] R. Folgieri, C. Lucchiari, M. Granato, and D. Grechi. Brain, Technology and Creativity. BrainArt: A BCI-Based Entertainment Tool to Enact Creativity and Create Drawing from Cerebral Rhythms. In *Digital Da Vinci*, pages 65–97. Springer New York, New York, NY, 2014.

[94] R. Folgieri and R. Zampolini. BCI Promises in Emotional Involvement in Music and Games. *Computers in Entertainment*, 11(4):1–10, feb 2015.

[95] R. Folgieri and M. Zichella. A BCI-based application in music. *Computers in Entertainment*, 10(3):1–10, nov 2012.

[96] E. Freeman, J. R. Williamson, P. Kourtelos, and S. Brewster. Levitating particle displays with interactive voxels. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays*, PerDis '18, New York, NY, USA, 2018. Association for Computing Machinery.

[97] A. Friday, N. Davies, and C. Efstratiou. Reflections on long-term experiments with public displays. *Computer*, 45(5):34–41, 2012.

[98] B. Geethanjali, K. Adalarasu, A. Hemapraba, S. Pravin Kumar, and R. Rajasekeran. Emotion analysis using sam (self-assessment manikin) scale. *Biomedical Research (0970-938X)*, 28, 2017.

[99] V. Gentile, P. El Agroudy, E. Ergin, and S. Clinch. Pervasive displays research: What's next? *IEEE Pervasive Comput.*, 18(1):72–78, 2019.

[100] V. Gentile, S. Sorce, I. Elhart, and F. Milazzo. Plantxel: Towards a plant-based controllable display. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays*, PerDis '18, New York, NY, USA, 2018. Association for Computing Machinery.

[101] A. Girgensohn. A fast layout algorithm for visual video summaries. In *Multimedia and Expo, 2003. ICME '03. Proceedings. 2003 International Conference on*, volume 2, pages II–77–80 vol.2, July 2003.

[102] L. Goddard, L. Pring, and N. Felmingham. The effects of cue modality on the quality of personal memories retrieved. *Memory*, 13(1):79–86, 2005. PMID: 15724909.

[103] P. Gomes, T. Pereira, and J. Conde. Musical emotions in the brain-a neurophysiological study. *Neurophysiology Research*, 1(1), 2018.

[104] T. Goto, S. Das, K. Wolf, P. Lopes, Y. Kurita, and K. Kunze. Accelerating skill acquisition of two-handed drumming using pneumatic artificial muscles. In *Proceedings of the Augmented Humans International Conference, AH 2020, Kaiserslautern, Germany, 16-17 March, 2020*, pages 12:1–12:9. ACM, 2020.

[105] R. Gouveia and E. Karapanos. Footprint tracker: Supporting diary studies with lifelogging. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, pages 2921–2930, New York, NY, USA, 2013. ACM.

[106] R. Gray, D. Budden-Potts, and F. Bourke. Reconsolidation of traumatic memories for ptsd: A randomized controlled trial of 74 male veterans. *Psychotherapy Research*, 29:621 – 639, 2019.

[107] R. L. Gregory. Distortion of visual space as inappropriate constancy scaling. *Nature*, 199:678–680, 1963.

[108] M. Greis, P. E. Agroudy, H. Schuff, T. Machulla, and A. Schmidt. Decision-making under uncertainty: How the amount of presented uncertainty influences user behavior. In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction, Gothenburg, Sweden, October 23 - 27, 2016*, page 52. ACM, 2016.

[109] R. Gross, E. Airoldi, B. Malin, and L. Sweeney. Integrating utility into face de-identification. In *Proceedings of the 5th International Conference on Privacy Enhancing Technologies*, PET'05, pages 227–242, Berlin, Heidelberg, 2006. Springer-Verlag.

[110] D. Gunning. Explainable artificial intelligence (xai). *Defense Advanced Research Projects Agency (DARPA), nd Web*, 2, 2017.

[111] C. Gurrin, H. Joho, F. Hopfgartner, L. Zhou, and R. Albatal. Ntcir lifelog: The first test collection for lifelog research. In *Proceedings of the 39th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '16, page 705–708, New York, NY, USA, 2016. Association for Computing Machinery.

[112] C. Gurrin, A. F. Smeaton, and A. R. Doherty. Lifelogging: Personal big data. *Foundations and Trends® in Information Retrieval*, 8(1):1–125, 2014.

[113] C. Gurrin, A. F. Smeaton, Z. Qiu, and A. Doherty. Exploring the technical challenges of large-scale lifelogging. In *Proceedings of the 4th International SenseCam Pervasive Imaging Conference*, SenseCam '13, page 68–75, New York, NY, USA, 2013. Association for Computing Machinery.

[114] O. L. Haimson, B. Semaan, B. Dym, J. C.-Y. Hsiao, D. Herron, and W. Moncur. Life transitions and social technologies: Research and design

for times of life change. In *Conference Companion Publication of the 2019 on Computer Supported Cooperative Work and Social Computing*, CSCW '19, page 480–486, New York, NY, USA, 2019. Association for Computing Machinery.

[115] S. S. Haraburda. The "seven sins of memory" how they affect your program. *HUMAN CAPITAL MANAGEMENT Defense AT&L*, 36(1):30–32, 2007.

[116] M. Harvey, M. Langheinrich, and G. Ward. Remembering through lifelogging: A survey of human memory augmentation. *Pervasive and Mobile Computing*, 27:14 – 26, 2016.

[117] R. Hasan, E. Hassan, Y. Li, K. Caine, D. J. Crandall, R. Hoyle, and A. Kapadia. Viewer experience of obscuring scene elements in photos to enhance privacy. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, pages 47:1–47:13, New York, NY, USA, 2018. ACM.

[118] M. Hassib, M. Khamis, S. Friedl, S. Schneegass, and F. Alt. Brainatwork: logging cognitive engagement and tasks in the workplace using electroencephalography. In *Proceedings of the 16th International Conference on Mobile and Ubiquitous Multimedia - MUM '17*, pages 305–310, New York, New York, USA, 2017. ACM Press.

[119] M. Hassib, M. Khamis, S. Schneegass, A. S. Shirazi, and F. Alt. Investigating user needs for bio-sensing and affective wearables. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '16, pages 1415–1422, New York, NY, USA, 2016. ACM.

[120] M. Hassib, S. Schneegass, P. Eiglsperger, N. Henze, A. Schmidt, and F. Alt. EngageMeter: A System for Implicit Audience Engagement Sensing Using Electroencephalography. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, pages 5114–5119, New York, New York, USA, 2017. ACM Press.

[121] E. Hayashi, R. Dhamija, N. Christin, and A. Perrig. Use your illusion: Secure authentication usable anywhere. In *Proceedings of the 4th Symposium on Usable Privacy and Security*, SOUPS '08, pages 35–45, New York, NY, USA, 2008. ACM.

[122] J. Henrich, S. J. Heine, and A. Norenzayan. The weirdest people in the world? *Behavioral and brain sciences*, 33(2-3):61–83, 2010.

[123] N. Henze, M. Pielot, B. Poppinga, T. Schinke, and S. Boll. My app is an experiment: Experience from user studies in mobile app stores. *International Journal of Mobile Human Computer Interaction (IJMHCI)*, 3(4):71–91, 2011.

[124] J. Hernandez, Z. Liu, G. Hulten, D. DeBarr, K. Krum, and Z. Zhang. Measuring the engagement level of tv viewers. In *2013 10th IEEE International Conference and Workshops on Automatic Face and Gesture Recognition (FG)*, volume 00, pages 1–7, 04 2013.

[125] D. Herron, W. Moncur, M. Curic, D. Grubisic, O. Vistica, and E. V. D. Hoven. Digital possessions in the museum of broken relationships. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, 2018.

[126] D. Herron, W. Moncur, and E. V. D. Hoven. Digital decoupling and disentangling: Towards design for romantic break up. *Proceedings of the 2017 Conference on Designing Interactive Systems*, 2017.

[127] D. Herron, W. Moncur, and E. Van Den Hoven. Digital decoupling and disentangling: towards design for romantic break up. In *Proceedings of the 2017 Conference on Designing Interactive Systems*, pages 1175–1185, 2017.

[128] D. Herron, W. Moncur, and E. van den Hoven. Digital decoupling and disentangling: Towards design for romantic break up. In O. Mival, M. Smyth, and P. Dalsgaard, editors, *Proceedings of the 2017 Conference on Designing Interactive Systems, DIS '17, Edinburgh, United Kingdom, June 10-14, 2017*, pages 1175–1185. ACM, 2017.

[129] N. Hesse. Mensch ärgere dich nicht. In *Spielend gewinnen*, pages 55–56. Springer, 2015.

[130] S. Hodges, L. Williams, E. Berry, S. Izadi, J. Srinivasan, A. Butler, G. Smyth, N. Kapur, and K. Wood. Sensecam: A retrospective memory aid. In *International Conference on Ubiquitous Computing*, pages 177–193. Springer, 2006.

[131] O. V. Hove, A. V. Muylem, V. Andrianopoulos, D. Leduc, V. Feipel, G. Deboeck, and B. Bonnechère. The use of cognitive mobile games to assess the interaction of cognitive function and breath-hold. *Respiratory Physiology & Neurobiology*, 274, 2020.

[132] R. Hoyle, R. Templeman, D. Anthony, D. Crandall, and A. Kapadia. Sensitive lifelogs: A privacy analysis of photos from wearable cameras. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, CHI '15, pages 1645–1648, New York, NY, USA, 2015. ACM.

[133] R. Hoyle, R. Templeman, S. Armes, D. Anthony, D. Crandall, and A. Kapadia. Privacy behaviors of lifeloggers using wearable cameras. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '14, pages 571–582, New York, NY, USA, 2014. ACM.

[134] S. Hsu, K. Vaccaro, Y. Yue, A. Rickman, and K. Karahalios. Awareness, navigation, and use of feed control settings online. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, pages 1–13, 2020.

[135] J. Huang, C. Yu, Y. Wang, Y. Zhao, S. Liu, C. Mo, J. Liu, L. Zhang, and Y. Shi. Focus: Enhancing children's engagement in reading by using contextual bci training sessions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, page 1905–1908, New York, NY, USA, 2014. Association for Computing Machinery.

[136] P. Ilia, I. Polakis, E. Athanasopoulos, F. Maggi, and S. Ioannidis. Face/off: Preventing privacy leakage from photos in social networks. In *Proceedings of the 22Nd ACM SIGSAC Conference on Computer and Communications Security*, CCS '15, pages 781–792, New York, NY, USA, 2015. ACM.

[137] Y. Jansen, J. Schjerlund, and K. Hornbæk. *Effects of Locomotion and Visual Overview on Spatial Memory When Interacting with Wall Displays*, page 1–12. Association for Computing Machinery, New York, NY, USA, 2019.

[138] S. Jiang, Z. Li, P. Zhou, and M. Li. Memento: An emotion-driven lifelogging system with wearables. *ACM Transactions on Sensor Networks (TOSN)*, 15(1):1–23, 2019.

[139] K. Jones, W. Crozier, and D. Strange. Believing is seeing: Biased viewing of body-worn camera footage. *Journal of applied research in memory and cognition*, 6:460–474, 2017.

[140] M. Jurmu, J. Goncalves, J. Riekki, and T. Ojala. Exploring use and appropriation of a non-moderated community display. In *Proceedings of*

the 13th International Conference on Mobile and Ubiquitous Multimedia, pages 107–115. ACM, 2014.

[141] F. Kalbe, S. Bange, A. P. C. Lutz, and L. Schwabe. Expectancy violation drives memory boost for stressful events. *Psychological Science*, 31:1409 – 1421, 2020.

[142] V. Kalnikaite, A. Sellen, S. Whittaker, and D. Kirk. Now let me see where i was: understanding how lifelogs mediate memory. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 2045–2054, 2010.

[143] J. Karolus and P. W. Wozniak. Proficiency-aware systems: Designing for user reflection in context-aware systems. *it Inf. Technol.*, 63(3):167–175, 2021.

[144] P. Kelly, A. R. Doherty, A. F. Smeaton, C. Gurrin, and N. E. O'Connor. The colour of life: novel visualisations of population lifestyles. In *Proceedings of the 18th ACM international conference on Multimedia*, pages 1063–1066, 2010.

[145] O. Khalaf, S. Resch, L. Dixsaut, V. Gorden, L. Glauser, and J. Gräff. Reactivation of recall-induced neurons contributes to remote fear memory attenuation. *Science*, 360:1239 – 1242, 2018.

[146] I. Khan, S. Khusro, N. Ullah, and S. Ali. Autolog: Toward the design of a vehicular lifelogging framework for capturing, storing, and visualizing lifebits. *IEEE Access*, 8:136546–136559, 2020.

[147] P. Khoshdani. From lab to the wild – conducting psychological experiments in the large, 2016. Master Thesis.

[148] H. Kim, C. Coutrix, and A. Roudaut. Knobslider: Design of a shape-changing ui for parameter control. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, pages 339:1–339:13, New York, NY, USA, 2018. ACM.

[149] Y. Kleiman, J. Lanir, D. Danon, Y. Felberbaum, and D. Cohen-Or. *DynamicMaps: Similarity-Based Browsing through a Massive Set of Images*, page 995–1004. Association for Computing Machinery, New York, NY, USA, 2015.

[150] W. Klimesch. Eeg alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain Research Reviews*, 29(2):169–195, 1999.

[151] M. Koelle, M. Kranz, and A. Möller. Don't look at me that way!: Understanding user attitudes towards data glasses usage. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '15, pages 362–372, New York, NY, USA, 2015. ACM.

[152] A. Koivisto, A. Lindstedt, S. Merilampi, and K. Kiili. Designing working memory games for elderly. In *GALA*, 2016.

[153] M. Korayem, R. Templeman, D. Chen, D. Crandall, and A. Kapadia. Enhancing lifelogging privacy by detecting screens. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, pages 4309–4314, New York, NY, USA, 2016. ACM.

[154] O. Lahav, V. Talis, R. G. Cinamon, and A. Rizzo. Virtual interactive consulting agent to support freshman students in transition to higher education. *Journal of Computing in Higher Education*, 32:330–364, 2020.

[155] Lancel/Maat. Lancel/Maat - E.E.G. KISS, 2014.

[156] C. Lander, A. Krüger, and M. Löchtefeld. "the story of life is quicker than the blink of an eye": Using corneal imaging for life logging. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, UbiComp '16, page 1686–1695, New York, NY, USA, 2016. Association for Computing Machinery.

[157] H. V. Le. Development and evaluation of automatic video recaps from lifelog data, 2015. Master Thesis.

[158] H. V. Le, S. Clinch, C. Sas, T. Dingler, N. Henze, and N. Davies. Impact of video summary viewing on episodic memory recall: Design guidelines for video summarizations. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, pages 4793–4805, New York, NY, USA, 2016. ACM.

[159] T.-K. Le, V.-T. Ninh, D.-T. Dang-Nguyen, M.-T. Tran, L. Zhou, P. Redondo, S. Smyth, and C. Gurrin. Lifeseeker: Interactive lifelog search engine at lsc 2019. In *Proceedings of the ACM Workshop on Lifelog Search Challenge*, pages 37–40, 2019.

[160] H. Lee, A. F. Smeaton, N. E. O'connor, G. Jones, M. Blighe, D. Byrne, A. Doherty, and C. Gurrin. Constructing a sensecam visual diary as a media process. *Multimedia Systems*, 14(6):341–349, 2008.

[161] M. L. Lee and A. K. Dey. Lifelogging memory appliance for people with episodic memory impairment. In *Proceedings of the 10th International Conference on Ubiquitous Computing*, UbiComp '08, pages 44–53, New York, NY, USA, 2008. ACM.

[162] S. Lee, H. Kim, and G. Lee. Ubigraphy: A third-person viewpoint life log. In *CHI'08 Extended Abstracts on Human Factors in Computing Systems*, pages 3531–3536. 2008.

[163] I. Li, A. Dey, and J. Forlizzi. A stage-based model of personal informatics systems. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 557–566, 2010.

[164] Y. Li, W. Troutman, B. P. Knijnenburg, and K. Caine. Human perceptions of sensitive content in photos. In *The IEEE Conference on Computer Vision and Pattern Recognition (CVPR) Workshops*, June 2018.

[165] Y. Li, N. Vishwamitra, H. Hu, B. P. Knijnenburg, and K. Caine. Effectiveness and users' experience of face blurring as a privacy protection for sharing photos via online social networks. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 61(1):803–807, 2017.

[166] Y. Li, N. Vishwamitra, B. P. Knijnenburg, H. Hu, and K. Caine. Blur vs. block: Investigating the effectiveness of privacy-enhancing obfuscation for images. In *2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, pages 1343–1351, July 2017.

[167] Y. Li, N. Vishwamitra, B. P. Knijnenburg, H. Hu, and K. Caine. Effectiveness and users' experience of obfuscation as a privacy-enhancing technology for sharing photos. *Proc. ACM Hum.-Comput. Interact.*, 1(CSCW):67:1–67:24, Dec. 2017.

[168] S. E. Lindley, M. Glancy, R. Harper, D. Randall, and N. Smyth. "oh and how things just don't change, the more things stay the same": Reflections on sensecam images 18 months after capture. *International Journal of Human-Computer Studies*, 69(5):311–323, 2011.

[169] Lisa Park. Eunoia — LISA PARK, 2013.

[170] C. H. Liu, C. Stevens, S. H. Wong, M. Yasui, and J. A. Chen. The prevalence and predictors of mental health diagnoses and suicide among us college students: Implications for addressing disparities in service use. *Depression and anxiety*, 36(1):8–17, 2019.

[171] Y. Liu, K. P. Gummadi, B. Krishnamurthy, and A. Mislove. Analyzing facebook privacy settings: user expectations vs. reality. In *Proceedings of the 2011 ACM SIGCOMM conference on Internet measurement conference*, pages 61–70, 2011.

[172] E. Loftus. Memory distortion and false memory creation. *The Bulletin of the American Academy of Psychiatry and the Law*, 24 3:281–95, 1996.

[173] T. Maekawa. A sensor device for automatic food lifelogging that is embedded in home ceiling light: A preliminary investigation. In *2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops*, pages 405–407. IEEE, 2013.

[174] A. Mair, M. Poirier, and M. A. Conway. Memory for staged events: Supporting older and younger adults' memory with sensecam. *Quarterly Journal of Experimental Psychology*, 72(4):717–728, 2019.

[175] T. Makada, D. Ozair, M. Mohammed, and C. Abellanoza. Enhancing memory retention by increasing alpha and decreasing beta brainwaves using music. In *Proceedings of the 9th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, PETRA '16, New York, NY, USA, 2016. Association for Computing Machinery.

[176] E. Makled, A. Yassien, P. Elagroudy, M. Magdy, S. Abdennadher, and N. Hamdi. Pathogenius VR: VR medical training. In *Proceedings of the 8th ACM International Symposium on Pervasive Displays, PerDis 2019, Palermo, Italy, June 12-14, 2019*, pages 31:1–31:2. ACM, 2019.

[177] M. Marchesi and B. Riccò. BRAVO: a brain virtual operator for education exploiting brain-computer interfaces. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA '13*, page 3091, New York, New York, USA, 2013. ACM Press.

[178] G. Meditskos, P.-M. Plans, T. G. Stavropoulos, J. Benois-Pineau, V. Buso, and I. Kompatsiaris. Multi-modal activity recognition from egocentric vision, semantic enrichment and lifelogging applications for the care of dementia. *Journal of Visual Communication and Image Representation*, 51:169–190, 2018.

[179] N. Memarovic. Interacting places- tools and interfaces for facilitating community interaction through public displays. PhD Colloquium@ Community Informatics, 2011.

[180] N. Memarovic, I. Elhart, and M. Langheinrich. Funsquare: First experiences with autopoiesic content. In *Proceedings of the 10th International Conference on Mobile and Ubiquitous Multimedia*, pages 175–184, 2011.

[181] N. Memarovic, M. Langheinrich, and F. Alt. The interacting places framework: conceptualizing public display applications that promote community interaction and place awareness. In *Proceedings of the 2012 International Symposium on Pervasive Displays*, pages 1–6, 2012.

[182] N. Memarovic, M. Langheinrich, E. Rubegni, A. David, and I. Elhart. Designing interacting places for a student community using a communicative ecology approach. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*, page 43. ACM, 2012.

[183] D. M. S. . Metrics. Social media users in egypt: Facebook insights and usage in egypt, 2018. Article, 2018. Retrieved December 12, 2019 from `https://www.digitalmarketingcommunity.com/indicators/facebook-insights-usage-in-egypt-2018/`,.

[184] M. Mikusz, S. Clinch, P. Shaw, N. Davies, and P. Nurmi. Using pervasive displays to aid student recall-reflections on a campus-wide trial. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays*, page 6. ACM, 2018.

[185] H. C. Min and T.-J. Nam. Biosignal sharing for affective connectedness. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '14, pages 2191–2196, New York, NY, USA, 2014. ACM.

[186] R. Misra and M. McKean. College students' academic stress and its relation to their anxiety, time management, and leisure satisfaction. *American journal of Health studies*, 16(1):41, 2000.

[187] S. R. Mitroff, A. T. Biggs, S. H. Adamo, E. W. Dowd, J. Winkle, and K. Clark. What can 1 billion trials tell us about visual search? *Journal of experimental psychology: human perception and performance*, 41(1):1, 2015.

[188] W. Moncur, K. M. Orzech, and F. G. Neville. Fraping, social norms and online representations of self. *Computers in Human Behavior*, 63:125–131, 2016.

[189] M. Mondal, J. Messias, S. Ghosh, K. P. Gummadi, and A. Kate. Forgetting in social media: Understanding and controlling longitudinal exposure of

socially shared data. In *Twelfth Symposium on Usable Privacy and Security ({SOUPS} 2016)*, pages 287–299, 2016.

[190] B. J. Moreton and G. Ward. Time scale similarity and long-term memory for autobiographical events. *Psychonomic Bulletin & Review*, 17(4):510–515, 2010.

[191] J. Müller, D. Wilmsmann, J. Exeler, M. Buzeck, A. Schmidt, T. Jay, and A. Krüger. Display blindness: The effect of expectations on attention towards digital signage. In *International conference on pervasive computing*, pages 1–8. Springer, 2009.

[192] J. Niess, P. W. Wozniak, Y. Abdelrahman, P. ElAgroudy, Y. Abdrabou, C. Eckerth, S. Diefenbach, and K. Knaving. 'i don't need a goal': Attitudes and practices in fitness tracking beyond weird user groups. In *MobileHCI '21: Proceedings of the 23rd International Conference on Human-Computer Interaction with Mobile Devices and Services, Toulouse, France, September 27 - October 1, 2021*. ACM, 2021.

[193] E. Niforatos, I. Elhart, and M. Langheinrich. Public displays for monitoring and improving community wellbeing. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*, pages 775–778. ACM, 2015.

[194] E. Niforatos, M. Langheinrich, and A. Bexheti. My good old kodak: understanding the impact of having only 24 pictures to take. In *Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing: Adjunct Publication*, pages 1355–1360, 2014.

[195] E. Niforatos, V. Lim, C. Vuerich, M. Langheinrich, and A. Bexheti. Pulsecam: biophysically driven life logging. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*, pages 1002–1009, 2015.

[196] M. Nilsen, M. Lundin, C. Wallerstedt, and N. Pramling. Evolving and re-mediated activities when preschool children play analogue and digital memory games. *Early Years*, 41:232 – 247, 2018.

[197] P. Nontasil and S. J. Payne. Emotional utility and recall of the facebook news feed. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pages 1–9, 2019.

[198] A. Nutsi and M. Koch. Interaction (f)or recall? evaluating recall on large screens. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '20, New York, NY, USA, 2020. Association for Computing Machinery.

[199] J. R. Padilla-López, A. A. Chaaraoui, F. Gu, and F. Flórez-Revuelta. Visual privacy by context: proposal and evaluation of a level-based visualisation scheme. *Sensors*, 15(6):12959–12982, 2015.

[200] P. Panhey, T. Döring, S. Schneegass, D. Wenig, and F. Alt. What people really remember: Understanding cognitive effects when interacting with large displays. In *Proceedings of the 2015 International Conference on Interactive Tabletops Surfaces*, ITS '15, page 103–106, New York, NY, USA, 2015. Association for Computing Machinery.

[201] P. Pedamkar. Types of research methodology. `https://www.educba.com/types-of-research-methodology/`. Last accessed: 2021-05-21.

[202] S. Phadke and T. Mitra. *Many Faced Hate: A Cross Platform Study of Content Framing and Information Sharing by Online Hate Groups*, page 1–13. Association for Computing Machinery, New York, NY, USA, 2020.

[203] P. Piasek, K. Irving, and A. F. Smeaton. Case study in sensecam use as an intervention technology for early-stage dementia. *International Journal of Computers in Healthcare 1*, 1(4):304–319, 2012.

[204] P. Piasek, K. Irving, and A. F. Smeaton. Using lifelogging to help construct the identity of people with dementia. 2014.

[205] H. Profita, R. Albaghli, L. Findlater, P. Jaeger, and S. K. Kane. The at effect: How disability affects the perceived social acceptability of head-mounted display use. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, pages 4884–4895, New York, NY, USA, 2016. ACM.

[206] U. Pruchniewska. "a group that's just women for women": Feminist affordances of private facebook groups for professionals. *new media & society*, page 1461444818822490, 2019.

[207] C. Qu and C. Sas. Exploring memory interventions in depression through lifelogging lens. In *Proceedings of the 32nd International BCS Human Computer Interaction Conference*, HCI '18, Swindon, GBR, 2018. BCS Learning Development Ltd.

[208] R. Rawassizadeh. *A holistic multi-purpose life logging framework*. PhD thesis, uniwien, 2012.

[209] J. Reason. The contribution of latent human failures to the breakdown of complex systems. In *Human error in aviation*, pages 5–14. Routledge, 2017.

[210] K. Reda, A. E. Johnson, M. E. Papka, and J. Leigh. *Effects of Display Size and Resolution on User Behavior and Insight Acquisition in Visual Exploration*, page 2759–2768. Association for Computing Machinery, New York, NY, USA, 2015.

[211] B. Reeves and C. Nass. *The media equation: How people treat computers, television, and new media like real people*. Cambridge university press Cambridge, United Kingdom, 1996.

[212] C.-H. Rhee and C. LEE. Cartoon-like avatar generation using facial component matching. *Int. J. of Multimedia and Ubiquitous Engineering*, 8(4):69–78, 2013.

[213] B. Rhorbach. Creative according to rules: Method 635, a new technique for solving problems. *sales economy*, 12:73–75, 1969.

[214] C. Robinson and R. Pond. Do online support groups for grief benefit the bereaved? systematic review of the quantitative and qualitative literature. *Comput. Hum. Behav.*, 100:48–59, 2019.

[215] F. Roesner, D. Molnar, A. Moshchuk, T. Kohno, and H. J. Wang. World-driven access control for continuous sensing. In *Proceedings of the 2014 ACM SIGSAC Conference on Computer and Communications Security*, CCS '14, pages 1169–1181, New York, NY, USA, 2014. ACM.

[216] S. H. M. Roffeei, N. Abdullah, and S. K. R. Basar. Seeking social support on facebook for children with autism spectrum disorders (asds). *International journal of medical informatics*, 84(5):375–385, 2015.

[217] O. Roth-Cohen. Viral feminism: #metoo networked expressions in feminist facebook groups. *Feminist Media Studies*, pages 1–17, 2021.

[218] J. Sadauskas, D. Byrne, and R. K. Atkinson. *Mining Memories: Designing a Platform to Support Social Media Based Writing*, page 3691–3700. Association for Computing Machinery, New York, NY, USA, 2015.

[219] S. A. Safwat, E. Osama, P. Elagroudy, and S. Abdennadher. Campusbuddy: how can campus public displays help students feel at home? In *Proceedings of the 8th ACM International Symposium on Pervasive Displays, PerDis 2019, Palermo, Italy, June 12-14, 2019*, pages 27:1–27:2. ACM, 2019.

[220] H. Sahibzada, E. Hornecker, F. Echtler, and P. T. Fischer. Designing interactive advertisements for public displays. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 2017.

[221] C. Sas, N. Davies, S. Clinch, P. Shaw, M. Mikusz, M. Steeds, and L. Nohrer. Supporting stimulation needs in dementia care through wall-sized displays. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, pages 1–16, 2020.

[222] C. Sas, T. Fratczak, M. Rees, H. Gellersen, V. Kalnikaite, A. Coman, and K. Höök. Affectcam: arousal-augmented sensecam for richer recall of episodic memories. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, pages 1041–1046. 2013.

[223] C. Sas and S. Whittaker. *Design for Forgetting: Disposing of Digital Possessions after a Breakup*, page 1823–1832. Association for Computing Machinery, New York, NY, USA, 2013.

[224] C. Sas, S. Whittaker, and J. Zimmerman. Design for rituals of letting go: An embodiment perspective on disposal practices informed by grief therapy. *ACM Trans. Comput. Hum. Interact.*, 23(4):21:1–21:37, 2016.

[225] C. Saucet and M. Villeval. Motivated memory in dictator games. *Games Econ. Behav.*, 117:250–275, 2019.

[226] D. L. Schacter. *The seven sins of memory: How the mind forgets and remembers*. HMH, 2002.

[227] A. J. Sellen, A. Fogg, M. Aitken, S. Hodges, C. Rother, and K. Wood. Do life-logging technologies support memory for the past?: an experimental study using sensecam. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 81–90. ACM, 2007.

[228] A. J. Sellen and S. Whittaker. Beyond total capture: a constructive critique of lifelogging. *Communications of the ACM*, 53(5):70–77, 2010.

[229] N. Sharifian and L. Zahodne. Daily associations between social media use and memory failures: the mediating role of negative affect. *The Journal of General Psychology*, 148:67 – 83, 2020.

[230] W. Shen, Z. Liu, L. J. Ball, T. Huang, Y. Yuan, H. Bai, and M. Hua. Easy to remember, easy to forget? the memorability of creative advertisements. *Creativity Research Journal*, 32(3):313–322, 2020.

[231] R. N. Shepard. Recognition memory for words, sentences, and pictures. *Journal of Verbal Learning and Verbal Behavior*, 6(1):156 – 163, 1967.

[232] S. M. Sherman, H. Follows, A. B. Mushore, K. Hampson-Jones, and K. Wright-Bevans. Television advertisements create false memories for competitor brands. *Journal of Applied Research in Memory and Cognition*, 4(1):1–7, 2015.

[233] S. L. Shipman, J. Nivala, J. D. Macklis, and G. Church. Crispr-cas encoding of a digital movie into the genomes of a population of living bacteria. *Nature*, 547:345 – 349, 2017.

[234] L. L. Sie-Yi and N. ChePa. Criteria of mobile psychotherapy games for memory disorder: A systematic literature review. *Int. J. Interact. Mob. Technol.*, 14:57–72, 2020.

[235] J. S. Soares and B. C. Storm. Forget in a flash: A further investigation of the photo-taking-impairment effect. *Journal of applied research in memory and cognition*, 7:154–160, 2017.

[236] C. Soliman. Speed reviewing visualizations of pictorial lifelogs, 2018. Bachelor Thesis.

[237] B. Sparrow, J. Liu, and D. M. Wegner. Google effects on memory: Cognitive consequences of having information at our fingertips. *science*, 333(6043):776–778, 2011.

[238] Statista. Number of internet users in egypt from 2013 to 2019 (in millions). Article, 2019. Retrieved December 12, 2019 from `https://www.statista.com/statistics/462957/internet-users-egypt/`,.

[239] J. Steil, M. Koelle, W. Heuten, S. Boll, and A. Bulling. Privaceye: Privacy-preserving first-person vision using image features and eye movement analysis. *CoRR*, abs/1801.04457, 2018.

[240] T. Stenovec. Steve mann was assaulted in a mcdonalds in (2012, france) for recording using google glass. `https://www.huffingtonpost.co.uk/2012/07/17/steve-mann-attacked-paris-mcdonalds-digital-eye-glass-photos_n_1680263.html`, 2012. Last accessed: 2019-05-15.

[241] B. Stinson and D. Arthur. A novel EEG for alpha brain state training, neurobiofeedback and behavior change. *Complementary Therapies in Clinical Practice*, 19(3):114–118, aug 2013.

[242] O. Storz, A. Friday, N. Davies, J. Finney, C. Sas, and J. Sheridan. Public ubiquitous computing systems: Lessons from the e-campus display deployments. *IEEE Pervasive Computing*, 5(3):40–47, 2006.

[243] I. Subramanian. Virtual parkinson's disease support groups in the covid-19 era: Social connection in the time of social distancing. *Movement Disorders Clinical Practice*, 7:739 – 740, 2020.

[244] D. Szafir and B. Mutlu. Pay attention!: Designing adaptive agents that monitor and improve user engagement. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, pages 11–20, New York, NY, USA, 2012. ACM.

[245] D. Szafir and B. Mutlu. ARTFul: adaptive review technology for flipped learning. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*, page 1001, New York, New York, USA, 2013. ACM Press.

[246] M. Tabassum, A. Alqhatani, M. Aldossari, and H. Richter Lipford. Increasing user attention with a comic-based policy. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, pages 200:1–200:6, New York, NY, USA, 2018. ACM.

[247] L. Taber and S. Whittaker. " on finsta, i can say'hail satan'": Being authentic but disagreeable on instagram. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, pages 1–14, 2020.

[248] H. Taiminen and K. Taiminen. Usage of facebook-and anonymous forum–based peer support groups online and their influence on perceived social support types in weight loss. In *2016 49th Hawaii International Conference on System Sciences (HICSS)*, pages 3094–3103. IEEE, 2016.

[249] D. I. Tamir and J. P. Mitchell. Disclosing information about the self is intrinsically rewarding. *Proceedings of the National Academy of Sciences*, 109(21):8038–8043, 2012.

[250] D. I. Tamir, E. M. Templeton, A. F. Ward, and J. Zaki. Media usage diminishes memory for experiences. *Journal of Experimental Social Psychology*, 76:161–168, 2018.

[251] H. Tankovska. Social media - statistics facts. https://www.statista.com/topics/1164/social-networks/. Last accessed: 2021-07-15.

[252] N. Taylor and K. Cheverst. Supporting community awareness with interactive displays. *Computer*, 45(5):26–32, 2012.

[253] R. Templeman, R. Hoyle, D. Crandall, and A. Kapadia. Reactive security: Responding to visual stimuli from wearable cameras. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication*, UbiComp '14 Adjunct, pages 1297–1306, New York, NY, USA, 2014. ACM.

[254] E. Thomaz, A. Parnami, J. Bidwell, I. Essa, and G. D. Abowd. Technological approaches for addressing privacy concerns when recognizing eating behaviors with wearable cameras. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '13, pages 739–748, New York, NY, USA, 2013. ACM.

[255] T.-D. Truong, T. Dinh-Duy, V.-T. Nguyen, and M.-T. Tran. Lifelogging retrieval based on semantic concepts fusion. In *Proceedings of the 2018 ACM Workshop on The Lifelog Search Challenge*, pages 24–29, 2018.

[256] E. Tulving. Synergistic ecphory in recall and recognition. *Canadian Journal of Psychology/Revue canadienne de psychologie*, 36(2):130, 1982.

[257] VICE. Artist Manipulates 48 Pools of Water with Her Mind - VICE, 2014.

[258] N. Vishwamitra, B. Knijnenburg, H. Hu, Y. P. Kelly Caine, et al. Blur vs. block: Investigating the effectiveness of privacy-enhancing obfuscation for images. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops*, pages 39–47, 2017.

[259] H. D. Wactlar. The challenges of continuous capture, contemporaneous analysis, and customized summarization of video content. *Computer Science Department, Carnegie Mellon Univeristy, Pittusburgh, PA*, 15213, 2001.

[260] K. A. Wade, M. Garry, J. D. Read, and D. S. Lindsay. A picture is worth a thousand lies: Using false photographs to create false childhood memories. *Psychonomic bulletin & review*, 9(3):597–603, 2002.

[261] T. Walter, R. Hourizi, W. Moncur, and S. Pitsillides. Does the internet change how we die and mourn? overview and analysis. *OMEGA-Journal of Death and Dying*, 64(4):275–302, 2012.

[262] P. Wang and A. F. Smeaton. Semantics-based selection of everyday concepts in visual lifelogging. *International Journal of Multimedia Information Retrieval*, 1(2):87–101, 2012.

[263] G. Ward, L. Tan, and R. Grenfell-Essam. Examining the relationship between free recall and immediate serial recall: The effects of list length and output order. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(5):1207, 2010.

[264] J. Warshaw, T. Matthews, S. Whittaker, C. Kau, M. Bengualid, and B. A. Smith. *Can an Algorithm Know the "Real You"? Understanding People's Reactions to Hyper-Personal Analytics Systems*, page 797–806. Association for Computing Machinery, New York, NY, USA, 2015.

[265] H. I. Weinberg, J. Wadsworth, and R. S. Baron. Demand and the impact of leading questions on eyewitness testimony. *Memory & Cognition*, 11(1):101–104, 1983.

[266] J. T. Wixted and E. B. Ebbesen. On the Form of Forgetting. *Psychological Science*, 2(6):409–415, 1991.

[267] C.-L. Wong. Retrieval-induced forgetting via social media: The mnemonic consequences of posting pictures on instagram. 2017.

[268] D. Wu, C.-Y. Li, and D.-Z. Yao. Scale-Free Music of the Brain. *PLoS ONE*, 4(6):e5915, jun 2009.

[269] S. Xiao, D. Metaxa, J. S. Park, K. Karahalios, and N. Salehi. Random, messy, funny, raw: finstas as intimate reconfigurations of social media. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, pages 1–13, 2020.

[270] S. Yan, G. Ding, H. Li, N. Sun, Y. Wu, Z. Guan, L. Zhang, and T. Huang. Enhancing Audience Engagement in Performing Arts Through an Adaptive Virtual Environment with a Brain-Computer Interface. In *Proceedings of the 21st International Conference on Intelligent User Interfaces - IUI '16*, pages 306–316, New York, New York, USA, 2016. ACM Press.

[271] A. Yassien, P. E. Agroudy, E. Makled, and S. Abdennadher. A design space for social presence in VR. In *NordiCHI '20: Shaping Experiences, Shaping Society, Proceedings of the 11th Nordic Conference on Human-Computer Interaction, Tallinn, Estonia, 25-29 October, 2020*, pages 8:1–8:12. ACM, 2020.

[272] A. Yassien, E. B. Makled, E. B. Makled, P. Elagroudy, N. Sadek, and S. Abdennadher. Give-me-a-hand: The effect of partner's gender on collaboration quality in virtual reality. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems, Virtual Event / Yokohama Japan, May 8-13, 2021*, pages 392:1–392:6. ACM, 2021.

[273] L. M. Zhou and C. Gurrin. A survey on life logging data capturing. *SenseCam 2012*, 2012.

[274] L. M. Zhou and C. Gurrin. Memorymesh: Lifelogs as densely linked hypermedia. In *Proceedings of the 4th International SenseCam Pervasive Imaging Conference*, SenseCam '13, page 90–91, New York, NY, USA, 2013. Association for Computing Machinery.

[275] Ícaro J.S. Ribeiro, R. Pereira, I. V. Freire, B. G. de Oliveira, C. A. Casotti, and E. N. Boery. Stress and quality of life among university students: A systematic literature review. *Health Professions Education*, 4(2):70 – 77, 2018.

APPENDICES

Appendix A

Framework Insights Summary

In this part, we collect all insights from the research projects representing the MACS use cases to simplify reviewing and synthesizing them. We use *MemAlt* pipeline as a reflection tool to compare and consolidate the findings (see Figure A.1). The details are presented in their respective chapters.

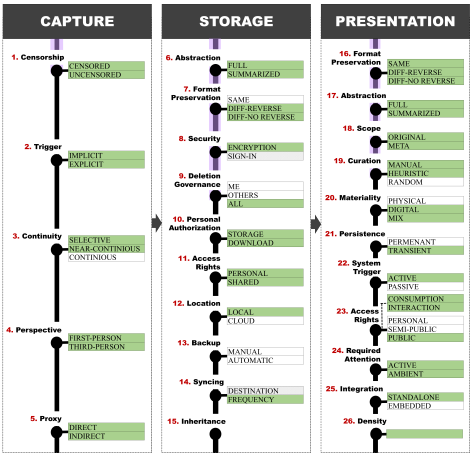
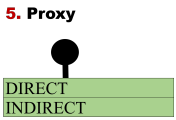


Figure A.1: Summary of the framework parameters we learnt about through the research project(s). The covered parameters are shaded in Green.

Table A.1: Framework findings inspired by all research project(s).

Parameter	Lessons Learnt
1. Censorship CENSORED UNCENSORED	**1.** (**RDT**) (`CENSORED`) Co-participants should be further considered in providing governance over capture. There were power conflicts between participants and co-participants when the latter were not comfortable about capturing common events. **2.** (**RDT**) (`UNCENSORED`) Participants tend to forget about the camera even when it captures sensitive situations such as toilet visits. **3.** (**LifeRewinder**) (`UNCENSORED`) Participants wanted to analyze the attitude of their social circle towards them as the passive photos capture genuine reactions of people. **4.** (**PPMCloak**) (`CENSORED`) Participants perceive body blurring as a sufficient technique to protect privacy while preserving aesthetics although it is known from prior work that it is ineffective in protecting privacy. **5.** (**PPMCloak**) (`CENSORED`) The wrongful or semi-correct remembering when using blurring coupled with the high confidence rates in the narrated memories is a promising and alarming effect as it implies the potential of using obfuscations for memory alterations.
2. Trigger IMPLICIT EXPLICIT	**6.** (**RDT**) (`IMPLICIT`) Co-participants often do not recognize that there is a camera automatically capturing them. **7.** (**RDT**) (`IMPLICIT`) The implicit nature of the capturing led co-participants to treating the camera as an active entity (e.g. saying hi to it for selfies) **8.** (**RDT**) (`EXPLICIT`) Co-participants tried to mimic explicit capturing through gesturing at the camera. However, this feature was not enabled in our experiment. Nevertheless, we think it is interesting to further explore its implications on social interaction. Participants were first welcoming of the interactions of the co-participants then seemed to be annoyed as time passed during the experiment.

Parameter	Lessons Learnt
3. Continuity SELECTIVE NEAR-CONTINIOUS CONTINIOUS	**9.** (**RDT**) (`SELECTIVE`) Participants proposed logging in special events only such as holidays or sports. **10.** (**RDT**) (`NEAR-CONTINUOUS`) Cameras are unable to warn users when the photos are occluded by clothes or hair. Thus, users needed to restrict their wardrobe choices and hair style which affected their experience negatively. **11.** (**RDT**) (`NEAR-CONTINUOUS`) As the camera is always on, a lot of the photos are blurry due to movement.
4. Perspective FIRST-PERSON THIRD-PERSON	**12.** (**RDT**) (`FIRST-PERSON`) Quality of captured photos is highly affected by the user's physique. Participants with shorter heights and larger busts are more prone to capturing occluded photos. **13.** (**PPMCloak**) (`THIRD-PERSON`) We ensured that every participant appeared at least once in the presented photos. This is important to ensure a baseline of having relatable cues in the photos to all participants. Thus, we opted for temporal deletion and blurring of everyone instead of deleting photos with specific participants. **14.** (**PPMCloak**) (`THIRD-PERSON`) We captured the photos using two opposing cameras covering the experimental area. We alternated the sampling between both cameras to maximize the angle coverage. We wanted to avoid scenarios like capturing the same participant from the back all the time.

Parameter	Lessons Learnt
	**15.** (**RDT**) (`DIRECT`) Participants cannot easily imagine the camera field of view. This creates disappointment as the captured photos do not match what "they see". Additionally, it prompts privacy breaches as they accidentally capture sensitive content. **16.** (**SpotlessMind**) (`INDIRECT`) Participants were negatively concerned about potential discord with others from inaccurate sensing of the mental state if the receivers believe it to be accurate. We speculate this is critical as the system senses a generic indirect cue, i.e the alpha wave, and uses it to label an abstract mental state, namely an occupied mind. Thus, concrete interpretations like assigning opinions to topics based on the system output were not welcomed as they may cause discord and hinder communication. **17.** (**CampusBuddy**) (`DIRECT/INDIRECT`) Regarding career inspiration, students preferred direct proxies such as showing advice about study programs and relevant jobs. However, academics preferred indirect generic proxies such as showing success stories. **18.** (**CampusBuddy**) (`DIRECT`) Regarding encouraging the trial of new activities, both students and academics preferred direct proxies about the activity regardless its type. **19.** (**CampusBuddy**) (`DIRECT`) Regarding enhancing familiarity with campus services, both academics and students preferred direct proxies such as announcements of upcoming events and study-related reminders such as class timings. **20.** (**CampusBuddy**) (`INDIRECT`) Academics proposed indirect proxies such as beautiful scenery and quotes to induce relaxation. **21.** (**PPMCloak**) (`DIRECT`) The collected lifelogs were direct proxies for the events in the first lab session. We tested the position of the camera to ensure it covers the full angle of the experimental area to include as many participants and session cues as possible.

Parameter	Lessons Learnt
6. Abstraction FULL SUMMARIZED	**22.** (**RDT**) (`SUMMARIZED`) The segmentation and selection of a representative photo per event is a time consuming and computationally expensive task. It took around four hours to process and generate the videos for a single day of photos on an core-i5 computer solely dedicated to the task. **23.** (**SpotlessMind**) (`SUMMARIZED`) EEGs generate high volumes of data that were not required in our case (128 Hz). We needed average values on larger time intervals so that the changes are perceivable by the audience and to account for the noise in the signal. Additionally, the original sampling rate would deplete our storage and transmission resources. Thus, we used averages of every 100 samples from the 8 electrodes. However, the downside of this approach is reducing the accuracy of the state detection as the alpha signals are not emitted uniformly in all the brain regions. **24.** (**PPMCloak**) (`FULL`) There is a trend of increased accuracy of memories' recollection in proportion with the quantity of photos shown followed by quality (Accuracy rates descendingly: original photos then blurred photos then incomplete dataset from deletion). The trend holds for recognition and recall scenarios. **25.** (**PPMCloak**) (`FULL`) There is a trend of increased confidence about recalled details in proportion with the quantity of photos shown followed by quality. The trend holds for recognition and recall scenarios. (Descending confidence rates: original photos then blurred photos then incomplete dataset from deletion).

Parameter	Lessons Learnt
7. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**26.** (**LifeRewinder**) (`DIFFERENT-REVERSE`) Transforming the photos into a video is technically tricky to implement varying speeds over time later as the developer will have to encode several versions of the video with varying speeds. **27.** (**SpotlessMind**) (`DIFFERENT-NO REVERSE`) We stored only the speed factors to protect the privacy of the participants as biological data is considered sensitive data and to avoid storage depletion. **28.** (**PPMCloak**) (`DIFFERENT-NO REVERSE`) Participants clearly preferred *body blurring* to other face and body obfuscation techniques in the context of environmental lifelogging. **29.** (**PPMCloak**) (`DIFFERENT-NO REVERSE`) Face blurring, body silhouette, body point-light, and body inpainting were the second most favoured obfuscation techniques for environmental lifelogs by the participants. **30.** (**PPMCloak**) (`DIFFERENT-NO REVERSE`) Face pixelating, face masking, body pixelating, body masking, and body bar were the least favoured obfuscation methods. **31.** (**PPMCloak**) (`DIFFERENT-NO REVERSE`) Participants negatively perceived the *avatar* technique in the context of environmental lifelogging. Face silhouette and face avatar were never selected in the top three obfuscation methods.
8. Security ENCRYPTION SIGN-IN	**32.** (**RDT**) (`ENCRYPTION`) The encryption and decryption process of the photos is a time consuming task. The decryption of one-week worth of data takes around 15 minutes on a core i5 computer.

Parameter	Lessons Learnt
9. Deletion Governance ME OTHERS ALL	**33.** (**RDT**) (`ALL`) Participants did not seem to care to post-delete photos in sensitive situations such as capturing passwords or being in the toilet. **34.** (**PPMCloak**) (`ALL`) Participants' confidence increased after seeing the original and blurred photos. However, their confidence in previously recalled answers decreased in case of C3 (deletion).
10. Personal Authorization STORAGE DOWNLOAD	**35.** (**RDT**) (`DOWNLOAD`) Almost half of our participants were not interested in retaining their dataset after the experiment because of the large space required. **36.** (**RDT**) (`DOWNLOAD`) The average size of the full dataset of a participant including his photos, time lapses and location data is 30 Gegabytes. **37.** (**PPMCloak**) (`STORAGE`) Participants were not allowed to contribute further photos to maintain the integrity of central lifelogs. **38.** (**PPMCloak**) (`DOWNLOAD`) We restricted the download of the captured photos to ensure the required information decay before testing their memory performance.
11. Access Rights PERSONAL SHARED	**39.** (**RDT**) (`SHARED`) Participants' acceptability of sharing their datasets shifted majorly throughout the experiment. Towards the end, almost half of them gave us access to their full dataset. **40.** (**SpotlessMind**) (`PERSONAL`) Only system administrators had access and control over the stored content. None of the stakeholders proposed downloadable content. **41.** (**CampusBuddy**) (`PERSONAL`) Only system administrators had access and control over the stored content. None of the stakeholders proposed downloadable content.

Parameter	Lessons Learnt
12. Location LOCAL CLOUD	**42.** (**RDT**) (`LOCAL`) Local storage only accessible by participants is crucial to encourage participants in longitudinal experiments like this.
14. Syncing DESTINATION FREQUENCY	**43.** (**RDT**) (`FREQUENCY`) The daily synchronization of the camera to the local computer took on average 15 minutes. **44.** (**SpotlessMind**) (`FREQUENCY`) Real-time data synchronization with commercial EEG caps is a challenging task. Thus, it is not recommended to use them for in-situ time-sensitive scenarios where accurate real-time feedback is required. Designers should also account for the delay while presenting the data for their use cases. We were reporting here on the general mental state. Thus, we were displaying delayed content in our proof-of-concept prototype.
16. Format Preservation SAME DIFF-REVERSE DIFF-NO REVERSE	**45.** (**RDT**) (`DIFF-REVERSE`) The implementation of the photos' buffer to support real time varying speed is a computationally expensive task. **46.** (**SpotlessMind**) (`DIFFERENT-NO REVERSE`) The content was captured as raw brain waves, then it was processed and displayed as interactive media without hashing the reversing equation to transform the speed factor back to raw waves. The transformation is to increase the understandability of the content and create an artistic experience out of it. The function is not reversible to protect the privacy of the participants and prevent the storage of critical biological data. **47.** (**CampusBuddy**) (`SAME`) The content was displayed in the same format it was captured and created in. The most commonly proposed formats were text and photos followed by videos. **48.** (**PPMCloak**) (`SAME`) Participants perceived aesthetics to have a strong impact on the acceptance of obfuscation in lifelogs.

Parameter	Lessons Learnt
17. Abstraction  	**49.** (**RDT**) (`SUMMARIZED`) Participants could not recognize the timelapse photos sometimes without their context. **50.** (**RDT**) (`SUMMARIZED`) Dividing photos by days in "LifeDome" reduced the search space during the search task in a weekly dataset. **51.** (**LifeRewinder**) (`SUMMARIZED`) Participants wanted to view only a subset of the dataset. For example, they suggested finding lost day-to-day gadgets using "quick" videos. **52.** (**SpotlessMind**) (`SUMMARIZED`) Abstract depictions are favourable for BO as they provide room for interpretation reducing misunderstandings from inaccurate sensing. **53.** (**SpotlessMind**) (`SUMMARIZED`) Concrete representations such as showing a graph of the BO or clearly marking the mental state of the partner cause privacy alerts. **54.** (**SpotlessMind**) (`SUMMARIZED`) Increasing speed is the commonly proposed mapping to an occupied mind. **55.** (**SpotlessMind**) (`SUMMARIZED`) Olfactory and gustatory representations of BO are best implemented by manipulating the intensity of the flavour or scent, where higher intensity corresponds to a busier mind. **56.** (**SpotlessMind**) (`SUMMARIZED`) Changes in BO represented via somatosensation were versatile, less intuitive and subject to opposing interpretations (E.g. does an increase in moistness correspond to busier or calmer mind state?) **57.** (**CampusBuddy**) (`FULL`) The proposed content was mostly static and we did not receive suggestions for interactive content on the displays. Thus, the stakeholders used it like a billboard rather than an interactive device although the researchers did not impose such constraint. **58.** (**PPMCloak**) (`FULL`) Blurring photos was objectively detrimental to correct recall of details because of guessing and wrongful cuing. **59.** (**PPMCloak**) (`FULL`) Participants perceived photos as "helpful" in enhancing their recall of memories even when they are obfuscated.

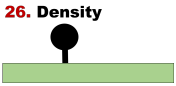
Parameter	Lessons Learnt
18. Scope ORIGINAL META	**60.** (**RDT**) (ORG) Full pictorial datasets in parallel reviewing using "Life-Dome" enabled participants to reflect on time spent doing tasks. **61.** (**RDT**) (ORG) Full pictorial datasets in parallel reviewing using "Life-Dome" enabled participants to recognize daily activities they missed otherwise in abstract versions like summarized video reviews. **62.** (**RDT**) (META) The search task of a representative photo for an event using "Life-Dome" was not mentally overloading. Participants took ca. 20-25 minutes to find photos for 20 events. Participants also reported it was easy. **63.** (**LifeRewinder**) (META) Parallel (grid) and sequential (speedy timelapse) reviewing were equally preferred for promoting a sense of productivity. **64.** (**LifeRewinder**) (META) Parallel (grid) and sequential (speedy timelapse) reviewing were equally preferred for getting an overview on daily activities. **65.** (**LifeRewinder**) (META) Participants proposed using **LifeRewinder** (sequential reviewing) for reflection to enhance time management **66.** (**LifeRewinder**) (META) Participants wanted to use **LifeRewinder** for learning and skill transfer. **67.** (**SpotlessMind**) (META) We communicated the concept of BO to non-technical users via processed abstract representations rather than showing the raw representations such as graphs for the brain signals marking the changes in the alpha waves. We speculate this allows them to focus on holistically and ambiently understanding the state via a leisure activity rather than focusing on interpreting the data. **68.** (**SpotlessMind**) (META) Although the majority proposed sweet depictions for olfaction and gustation, there was a division around its interpretation in relation to the BO. **69.** (**SpotlessMind**) (META) Participants particularly proposed using olfactory depicts to nudge others for semantic meta actions depending on the BO such as leaving the person alone rather than presenting the BO itself.

Parameter	Lessons Learnt
19. Curation MANUAL HEURISTIC RANDOM	**70.** (**RDT**) (`HEURISTIC`) Aesthetic metrics such as brightness and minimal blurriness do not always correspond to the most representative photo of an event for the participant. **71.** (**LifeRewinder**) (`HEURISTIC`) Participants proposed using **LifeRewinder** to track behavioural change related to body image. **72.** (**LifeRewinder**) (`HEURISTIC`) Participants proposed using **LifeRewinder** to review regular events with temporal dependency in the content such as lectures and work meetings. **73.** (**LifeRewinder**) (`HEURISTIC`) Participants wanted to review lecture notes and tutorials as well as others' curated experiences such as cooking. **74.** (**CampusBuddy**) (`HEURISTIC`) Academics recommended heuristically curating content promoting extracurricular activities to widen the students' horizons or relaxing content. **75.** (**CampusBuddy**) (`HEURISTIC`) Senior students preferred heuristically curating content focused around entertainment and news to gain control of the surroundings. **76.** (**CampusBuddy**) (`HEURISTIC`) Freshman students preferred heuristically curating content centered around campus information to increase familiarity with the university. **77.** (**CampusBuddy**) (`MANUAL`) In this project, we did not explore algorithms for heuristic curation or sources for capturing the content. The assumption is the final selection of the content is by a system administrator manually. However, one could also imagine automatic curation using preset heuristics.

Parameter	Lessons Learnt
20. Materiality PHYSICAL DIGITAL MIX	**78.** (**RDT**) (`DIGITAL`) We observed a novelty effect while using our prototypes, especially the "Life-Dome". Participants and co-participants were excessively interacting with the camera in the first week of the experiment. Additionally, participants were verbally commenting about how impressed and excited they are to "see their week at a glance". **79.** (**RDT**) (`DIGITAL`) Participants find it hard to grasp the expected angle of the camera even towards the end of the experiment. For example, they were still surprised when the content of their laptops showed in the weekly review photos. **80.** (**SpotlessMind**) (`MIX`) To represent BO, visual, auditory, and somatosensory representations are the most favourable. Olfactory depictions were also requested but there was a division in opinion about their favourability. However, gustatory depictions are the least favourable. **81.** (**SpotlessMind**) (`MIX`) Participants wanted to have multimodal sensory depictions of BO. **82.** (**SpotlessMind**) (`MIX`) Somatosensorics were particularly versatile and received numerous mapping suggestions for BO. **83.** (**CampusBuddy**) (`DIGTAL`) All the content was displayed only digitally. There were no suggestions of creating mixed experiences. However, we should carefully postulate about that as it might be an inherent limitation to the study design asking participants to design "on-the-screen" experience.

Parameter	Lessons Learnt
21. Persistence PERMENANT TRANSIENT	**84.** (**SpotlessMind**) (`TRANSIENT`) The proposed content in the setup was transient to focus on the mutual sharing moment and the theatrical nature of the setup. None of the stakeholders proposed the creation of permanent downloadable content. **85.** (**CampusBuddy**) (`TRANSIENT`) The proposed content by nature was transient as it was controlled by the system administrators most of the proposed content was contextual such as class reminders. None of the stakeholders proposed the creation of permanent downloadable content.
22. System Trigger ACTIVE PASSIVE	**86.** (**CampusBuddy**) (`ACTIVE`) The participants proposed automatically-displayed content without any interference from the viewers. They also proposed contextual content such as timely reminders before classes.
23. Access Rights CONSUMPTION INTERACTION PERSONAL SEMI-PUBLIC PUBLIC	**87.** (**LifeRewinder**) (`INTERACTION`) All participants found the knob easier to use than the keyboard and mouse controls. **88.** (**CampusBuddy**) (`INTERACTION`) The participants did not propose any interactive content or request specific interactions with the screen. We postulate this confirms the ambient nature of the display for them. **89.** (**CampusBuddy**) (`CONSUMPTION/PUBLIC`) Neither the academics nor the students proposed sharing personal content such as tweets about their university experience on the screens even after reviewing it. Instead, all groups proposed generic informative content.

Parameter	Lessons Learnt
24. Required Attention ACTIVE AMBIENT	**90.** (**LifeRewinder**) (`ACTIVE`) Participants thought sequential reviewing is useful for search and a quick overview. **91.** (**LifeRewinder**) (`ACTIVE`) Participants thought parallel reviewing is useful for inspecting details. **92.** (**CampusBuddy**) (`AMBIENT`) Academics perceive campus public displays as a distraction and overloading source of information. However, students find it useful for supporting behavioural change. **93.** (**PPMCloak**) (`ACTIVE`) Participants tended to update their answers after seeing the photos in recall questions more than recognition questions through all conditions. **94.** (**PPMCloak**) (`ACTIVE`) Results suggest that participants updated their answers in C1 (baseline) and C3 (deletion) only when they remembered the information without help of any cues, or when they saw explicit cues in the photos, leading to a higher ratio of correct answers.
25. Integration STANDALONE EMBEDDED	**95.** (**LifeRewinder**) (`STANDALONE`) Participants were particularly impressed by the "Life-Dome" prototype and called it an experience. They took the time to interact with it outside the experimental procedures without any encouragement or instructions from the researchers. **96.** (**CampusBuddy**) (`STANDALONE`) All the proposed content by our stakeholders was focused around a single theme at a time. We did not receive proposals from mixed experiences.

Parameter	Lessons Learnt
	**97.** (**RDT**) (`DURATION`) We showed each photo in the timelapse for 3 seconds conforming with prior work. **98.** (**RDT**) (`FREQUENCY`) Showing a timelapse summarizing a day once is not enough to intrinsically enhance recall. Further research should be done to identify the trade off factor between the number of required repetitions and an enjoyable user experience. **99.** (**RDT**) (`NUMBER OF CUES`) Each time lapse did not exceed 3 minutes conforming with prior work (40 - 60 photos max). **100.** (**RDT**) (`NUMBER OF CUES`) In parallel holistic reviewing (Like "Life-Dome"), photos should be small to avoid overloading participants with details and to enable mental parsing of events but large enough to pick salient details. **101.** (**RDT**) (`NUMBER OF CUES`) Mapping a day to limited visual units like 2 to 3 pages simplifies mental estimate of time spent on a task. **102.** (**SpotlessMind**) (`DURATION`) We pilot tested the system to ensure that the speed factor of the visual and auditory stimuli remain in comfortable levels at the two ends of the spectrum in BO. **103.** (**PPMCloak**) (`NUMBER OF CUES`) Participants subjectively prefer to have more photos even if they are distorted.

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List of Acronyms

AMV Automated Memory Validation

AR Augmented Reality

BCI Brain-Computer Interface

BO Brain occupancy

CIR Critical Incident Report

CMC Concealed Memory Collection

DRM Deese–Roediger–McDermott

EEG Electroencephalogram

FB Facebook

HCI Human-Computer Interaction

HMD Head Mounted Display

LL List length

MACS Memory-Altering ubiquitous-Computing Systems

MemAlt Memory Alteration Pipeline

MENA Middle East and North Africa

observer The bystanders watching the sharers

P_{hear} The sharer who hears an auditory depiction of brain occupancy

P_{see} The sharer who sees a visual depiction of brain occupancy

PPM Privacy-Protection Method

PTSD Post Traumatic Stress Disorder

QS Quantified Self

RCS Recall Correctness Score

RDT Recall Domestic Trial

RQ research question

RTM Reconsolidation of Traumatic Memories

SAM Self Assessment Manikin

SES Socio-Economic Status

sharer The two users simultaneously sharing their brain occupancy

UCS ubiquitous-computing system

UX User Experience

WEIRD Western-Educated-Industrialized-Rich-Democratic

Passant Elagroudy

Designing Ubiquitous-Computing Systems for Memory Alterations

Memories shape the identity of civilizations through shared knowledge. However, the increasing digital resources competing to generate content and alter what we remember threaten our natural mechanisms for forgetting inessentials to focus on what is important. In this work, we aim to understand the design process of memory-altering ubiquitous computing systems (MACS) and to raise awareness about accidental alterations from using technology.

With the help of 188 participants, we explore: 1) how to design MACS, 2) how to conduct privacy-aware memory research, and 3) the users' expectations for utilizing their memories by others and by AI systems.

We consolidate the design insights from eight projects to present “MemAlt”, a framework for designing MACS. We also develop two privacy-aware memory research methods to anonymously collect data and ubiquitously evaluate it. Additionally, we pin sharing expectations on social media to foresee patterns with memory technologies.

With the prevalence of tracking devices such as mobiles, fitness devices, and smart home gadgets, we envision a future where domain-specific MACS are ubiquitous in everyday interactions. Thus, this work makes designing MACS more accessible to researchers, and allows them to reflect on adverse effects of their designs on memory.

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