Memory Support through In-Home Display Deployment

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The authors propose the idea of memory displays deployed in people's homes that show aggregated information taken from personal datastreams to provide cues for recall and thereby support human memory.

The increasing popularity of wearable computing devices has given rise to the era of lifelogging technologies. Various sensors accompany users throughout the day, recording images, locations, movements, and environmental and physical data. What started with simple imaging systems[1] has long since been picked up by commercial vendors and resulted in a whole range of products—such as Fitbit (www.fitbit.com), Jawbone (https://jawbone.com), and mobile apps—that have fostered the quantified-self movement. Such fitness and health tracking has become a popular use case for smartphone apps, mainly to monitor and motivate behavior change. However, activity tracking goes beyond the purely physical realm: early versions of smartphones already comprised a rich set of productivity tools, such as personal calendars, reminders, or to-do lists.

As humans, we become accustomed to trusting technology with our cognitive tasks and using coherent cognitive systems, also known as *distributed cognition*.[2] Wearables such as smart glasses enable us to quantify cognitive activities—eye tracking, for instance, lets us track cognitive processes[3] as well as higher cognitive skills, such as reading.[4] Using electroencephalography (EEG), we can further sense brain activities such as learning and associated mental processes. With low-cost devices such as the Emotiv Insight

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Related Work in Lifelogging and Memory Aid

In his article "As We May Think," Vannevar Bush envisioned a device that held records, communications, and media as a complement to people's memory.[1] Implementing this vision requires comprehensive data collection, processing, and filtering. Comprehensive data collection, or *lifelogging*, is made possible mainly via wearable technologies. Steve Mann proposed the use of wearable cameras as a visual memory prosthetic.[2] Embedded in eyewear, they allow for real-life image capturing with the goal of creating a personal photo- or videographic memory prosthesis.[3] Jim Gemmell, Gordon Bell, and Roger Lueder constructed a lifelogging platform called *MyLifeBits* to investigate the efforts of digitizing an entire lifetime and storing its related documents.[4] Data considered includes a radio and TV capturing tool, location data, and the capture of analog content. A prominent tool to capture images for lifelogging purposes is the SenseCam, an on-body, sensor-enhanced camera that automatically takes pictures at a determined interval. Steve Hodges and his colleagues used the SenseCam in a 12-month clinical trial with a patient suffering from amnesia to review experiences that had been forgotten.[5]

These research efforts are accompanied by the development of a series of commercial products: wearable gadgets as well as smartphone applications that have helped spawn the so-called *quantified-self movement*. Many activity trackers are available, such as Fitbit for recording steps and calories burned, biophysiological data recording (such as Zephyr BioHarness), image capturing (for example, Narrative Clip), or the plentitude of sensors integrated in today's smartphones, watches, and eyewear, which allow for rich data collection. Many of these products and services provide proprietary interfaces to track their respective data and build a user community of sharing to foster motivational aspects for behavior change.

Carolina Cruz-Neira, Daniel Sandin, and Thomas DeFanti proposed virtual reality as a way to display data and support immersion.[6] Other pervasive awareness interfaces, such as calm and ambient displays, can be used for influencing people to make behavior changes by bringing previously inaccessible information to their attention. Sunny Consolvo, David McDonald, and James Landay proposed design strategies for persuasive technologies for behavior change.[7] They came up with a set of eight strategies: abstract/reflective, unobtrusive, public, aesthetic, positive, controllable, trending/historical, and comprehensive. These strategies are not meant to be mutually exclusive and can overlap. However, in addition to inspiring behavior change, making activity data accessible to users can also foster their memory. By bringing current goals as well as memories of positive experiences to the front of users' attention, we might be able to help people overcome initial motivational obstacles.

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neuroheadset (http://emotivinsight.com) being commercialized, such sensing becomes feasible on a larger scale. With the goal of optimizing our mental fitness and overall well-being, these technologies allow us to reminisce and engage in retrospection for memory strengthening.[5]

We define the approach of tracking activities in the wild beyond the physical realm as *mobile cognition*. It entails aggregating, preparing, and presenting collected data to augment human cognition. This process includes various disciplines, from big data processing for collection to machine learning for making sense of the data to visualization techniques for feeding that information to users. Wearables and mobile devices are key components for sensing, processing, and turning data into actionable information with the intention of supporting human memory. In this work, we take a human-centered perspective and focus on qualitative aspects of memory displays, such as the feasibility of content, display locations, and presentation modalities. We aim to combine physical and cognitive datasets to digitally recreate a holistic set of people's activities and use displays in people's homes to feed back that information. We can thus use this information as memory cues to trigger recall and invite people to engage in reminiscence and retrospection, as well as proactive remembering.

While many lifelogging applications focus on supporting people's past (retrospective) memory, strong evidence indicates that people are more challenged in remembering what they intend to do in the future (prospective memory).[6] Hence, a comprehensive memory aid should support users in recollecting memories and allow for reminiscing, targeted information retrieval, reflection on past experiences, and remembering prospective events. Our work focuses on the challenges of presentation: how to display personal context streams to people that let them reflect on days in the past but also prepare them for days ahead.

In this article, we outline our approach to deploying ambient, semipublic memory displays in people's homes that are connected to personal context streams, such as calendar information, location, movement data, and images taken. We discuss their function as retrospective summary tools and explore their potential for briefing or priming people for the day ahead. We present an explorative approach consisting of design explorations, a survey, and a test deployment of a prototype. To study memory display parameters such as location (where to put such displays in people's homes), content types (what to show), and presentation (how to show it), we built a system that can project an audiovisual dashboard in users' homes.

Using Personal Data to Support Human Cognition

Icek Ajzen has found that people are more likely to stick to a planned behavior if they are reminded of their own (positive) attitudes toward it.[7] Therefore, we use ambient or peripheral displays to show information relevant to prospective events throughout the user's day. The idea behind this is based on the *priming effect*.

Priming

The concept of *priming* describes an implicit memory effect in psychology: by exposing users to a current stimulus, the response to another stimulus is influenced in the future.[8] We combine this with the notion of déjà vu—defined in the Oxford dictionary as a feeling of having already experienced the present situation—to build proactive systems that prepare people's memories for what is to come. The goal of this concept is to make new situations and encounters appear more familiar and help build out multiple association points to which people can link new information. Priming has been successfully applied in computer systems before, namely in virtual realities: one study found subliminal priming to have a positive effect on users' performance in virtual tutoring environments.[9]

Retrospection

Contrary to priming, retrospective memory aids support the human memory by providing cues to the past. Tools for retrospection provide users with means to four of what Abigail Sellen and Steve Whittaker call the five R's[6]:

- recollecting (thinking back to past experiences, or episodic memory);
- reminiscing (reliving past experiences for sentimental reasons);
- retrieving (accessing specific information encountered in the past); and
- reflecting (reviewing past experiences with the goal to recognize).

The fifth R (remembering) describes the ability to remember prospective events as opposed to things that happened in the past, and falls therefore under what we categorize as a function of priming.

Personal Data

Personal data originates mainly from devices and sources that collect information and activity data on a specific person. This information can include locations visited, steps taken, sleep patterns, pictures taken, calendar entries, or communication data. Furthermore, this data can be enriched by external context information, such as location-specific weather reports or relevant news articles. The resulting personal content stream is subject to a number of privacy implications, an in-depth discussion of which would go beyond this article's scope. To preserve some of the user's privacy, our initial concept of memory displays focuses on semipublic deployments.

Display Parameters

Semipublic displays are typically found in environments such as people's homes or offices. As opposed to public displays, which are accessible to the general public—for example, in spaces such as train stations or market squares—semipublic displays can be accessed only by a limited number of people. They can be focused on a specific person or group and hence might contain rather personal context streams. Unlike private displays such as the mobile phone or a smartwatch, which are typically accessible to a single user, semipublic displays are deployed in the environment, serving as peripheral displays. Such displays can be placed in different locations throughout people's homes. As ambient displays, they move from the focus to the periphery of people's attention. Convenient locations are those that users pass frequently, such as hallways, the living room, or kitchen walls. However, placement can also depend on the display's purpose and content. The type of information displayed depends on the memory concept the display implements.

We distinguish between priming and retrospection. In our initial explorations, we focused on the different locations throughout people's homes where such displays could be placed, as well as the types of data to be visualized on memory displays, such as people's calendars, communications, past locations, and movement data. Furthermore, we looked at different presentation modalities of information—namely, visual, audio, and video and audio combined. To explore the design space of memory displays in such a way, we started with a design exploration task, conducted an online survey, and built a fully functional prototype that let us test these different modalities in the form of a smart alarm clock.

Concept and Scenarios

Peripheral memory displays collect activity data from wearables, mobile devices, and online sources and feed a processed summary of this information back to the user. This includes places visited, people encountered, or passages read. By showing users pictures of recent encounters alongside people's names and context-relevant information, such displays could help to strengthen face-recognition memory and commit details of an encounter to long-term memory. By repeatedly exposing users to their past activities, such displays aim to support people's episodic memory—that is, the capacity to remember specific events. They can be further used to enhance semantic memory, which is assumed to store accumulative knowledge of the world: displays deployed throughout the user's home can support learning tasks by presenting information relevant to a certain topic. For example, by showing vocabulary, language skills can be strengthened. Findings in language learning show how spaced exposure[10] and continued exposure[11] to stimuli result in greater learning gains. By combining semantic knowledge with lifelogging data, pervasive displays can help foster memory and move content from people's short-term to long-term memory.

To explore one specific scenario in more detail, we engaged students in a design task concerning the déjà vu effect. The basic idea is to facilitate users' ability to cope with new situations; visiting new places, getting to know new people, or engaging in new tasks is part of everyday life. Naturally, such situations create a sense of excitement or anxiety when people face the unknown. Our approach aims to utilize peripheral displays in the home to present small information chunks that potentially have future relevance for a person and lower the barrier to the unknown. We investigate whether people can learn incidentally and without conscious effort about new environments and people. By providing visual information on peripheral displays, we can create a sense of déjà vu for when people will actually face new situations.

To elaborate on this concept and explore the aforementioned display parameters, we engaged in a design task with nine students whom we asked to come up with déjà vu scenarios and

Figure 1. Mockups for display locations throughout a home. Displays can be placed in areas such as (a) a hallway, (b) a living room, or (c) on a refrigerator door.

mockups for placing interactive memory displays in the home. The mockups were based on the metaphor of traditional peripheral displays, such as stickies or pinboards. Figure 1 shows examples of resulting displays and their location. These examples show conceptual placements in hallways, in living rooms, and on refrigerator doors.

For example, one application scenario includes overcoming culture shock. When migrating for work or spending extended periods of time studying abroad, such change can be challenging. People often experience frustration and difficulty when adjusting to new cultural situations. Even the most basic daily tasks might require an unanticipated degree of adaptation and new learning.[12] Using a peripheral display showing a déjà vu board, a user can be warned about potential challenges and solutions offered by fellow travelers or expatriates who have had similar experiences. Local customs, rules, and regulations can be pointed out in advance by displaying text, images, or even short videos. Such rich multimedia examples can be used to illustrate what to expect and how to overcome those challenges. The déjà vu concept is a special case of using priming effects to prepare users for upcoming situations. The general application space is vast, so we began with exploring possibilities to prep users for their daily routines using in-house memory display deployment. The results were a first impression about where users would like memory displays to be placed (hallway, living room, or kitchen) and what types of content would be appropriate to display (location information, calendar entries, weather information, and so on).

Memory Display Exploration

To explore the design space of memory displays with a special focus on retrospection and utilizing the priming effect, we set out to build a display system for in-home deployment. From the previously described design exploration, we derived several system features, such as location information, calendar entries, and weather information. Next, we conducted an online survey to elicit information on daily habits and usage scenarios on a broader scale.

Online Survey

Through an online survey, we collected comments and ratings over the course of two weeks from 125 participants (48 women, 77 men) with a mean age of 28 ($SD = 8.06$). The survey aimed to elicit detailed information about the types of things people would like to be briefed on or reminded about in their everyday lives and which tools they currently use for that purpose. Furthermore, we presented the concept of an alarm clock as a bedside projection device that prepares users for their day when they wake up. The online survey consisted of 19 questions in total and was divided into three sections:

- introduction to lifelogging technologies, with general questions about experiences so far, self-reflection, and how future planning is generally being done;
- questions about a prototypical system; and
- questions about people's general wake-up habits and routines.

The types of answers collected included Likert-scale ratings, single and multiple choice selections, and free-form text.

The online survey results yielded preliminary insights for three general areas: lifelogging technology usage, reflection and daily planning activities, and subjective feedback on a general description of our proposed system. We asked participants what tools or technologies they were currently using that automatically recorded parts of their lives. Thirty-four percent mentioned apps such as Runtastic or Moves. However, a majority (66 percent) reported not using any lifelogging technologies. As to why people would record their lives in the first place, 58 percent of survey participants saw the potential to live healthier.

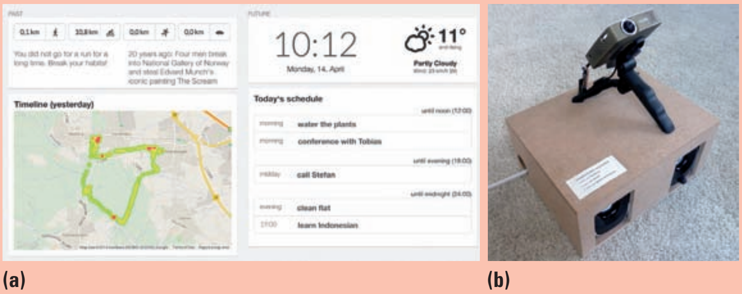

Figure 2. Memory display prototype. (a) The system dashboard shows a summary of movement data from the past, fitness goals, current weather information, and the day's schedule. (b) The physical prototype is a bedside device.

When asked what they would like to automatically record, participants indicated that photos (52 percent), locations (43 percent), and activities (38 percent) were most vital to them (participants could select multiple options). Regarding the nature of daily summaries, we asked people at which point during the day they would be most likely to engage in retrospection: 46 percent preferred such summaries in the evening, whereas 30 percent wanted them in the morning. Fifty-nine percent of participants indicated a willingness to spend around six minutes on retrospective activities, with a median of five minutes ($M = 5.81$, $SD = 5.58$). The majority of participants reported having a regular daily routine for which they planned their day in advance: 48 percent indicated following a regulated or very regulated daily routine, whereas 29 percent lived rather randomly day to day; 51 percent reported planning their day in advance most of the time or always. Sixty-nine percent mentioned organizing their daily life with a digital calendar, whereas only 22 percent used a conventional pocket calendar. Our online survey constituted results similar to a market study by Harris Interactive that found that the most commonly checked apps upon wake-up in the morning were email (67 percent), weather (45 percent), social media (40 percent), and news (35 percent).[13] From these numbers and the free-form feedback, we refined the concept of a system that helps people prepare for their day, which resulted in a working prototype alarm clock.

Prototype and Explorative User Study

After analyzing the design explorations described in conjunction with the subjective feedback we collected through the survey, we ended up with a set of key features for an initial memory display prototype. The system generates a personal content stream in the form of a dashboard (Figure 2) from two data sources: location data is retrieved from the Moves app, which is enriched with data from the Nominatim Reverse Geocoding API. To show a stream of personal images, we use Dropbox, a cloud storage provider that offers automatic camera uploads to its cloud storage. To retrieve calendar events, we access users' Google calendars. Additionally, we fetch local weather information from the online Forecast.io API (http://forecast.io).

Users authenticate all these data sources through the authorization framework OAuth without sharing any credentials. Our system periodically retrieves data from these sources and prepares the personal content stream. The content is then displayed through a bedside device equipped with a Raspberry Pi—a small projector and sound speakers, as Figure 2 shows. The Raspberry Pi runs a server that connects to the local Wi-Fi network. The device can be configured and alarms can be set via the corresponding mobile phone app or through a website. The visual display comprises information about recent movement patterns, compares it to current fitness goals as specified in the Moves app, and gives recommendations about keeping up with those goals. Furthermore, the display shows current weather information and the schedule for the day ahead. The visualization of the movement patterns and locations alternates with the display of pictures taken over the previous days. A corresponding audio presentation summarizes the dashboard via an in-built text-to-speech generator that reads out the most important information for the day ahead. The visual arrangement, along with the corresponding audio, is designed to give a brief overview without exceeding the five-minute retrospection time people are willing to spend at maximum, as determined through our survey.

To explore its feasibility and gather user feedback, we deployed the prototype in the households of six participants (three women, three men) with a mean age of 30 years (SD = 12.9). This pilot prototype offered different presentation modes—namely, visual, audio, and a combination of the two. We were interested in exploring the utility of daily summaries upon waking. Hence, we gave participants the prototype for six consecutive days. Every second day, the presentation mode changed from dashboard mode (purely visual), to speech mode, to a combination of visuals and audio. Beforehand, we collected lifelog data for seven days to feed the system with personalized content. After every two days, we interviewed participants about their wake-up experience. Four out of six participants wore glasses and needed to put them on before being able to read the displayed content. Hence, the purely visual mode was less well received. Five minutes seemed to be sufficient to consume the dashboard content. People preferred a combination of speech and a visual dashboard: speech was considered suitable for the first wake-up phase, after which the visual projection seemed to give a more holistic picture of the day. Participants reported an increased awareness of their data through the presence of the prototype. Throughout the 13 days (seven days of data collection in advance and six days of using the apparatus), we gathered on average 178 location coordinates (SD = 58.52), 13 activities (SD = 6.91), five location changes (SD = 1.18), and 1.5 images (SD = 1.07) per day.

To summarize, people welcomed the use of a morning briefing through an alarm clock. Due to the small scale of this initial study, we cannot deduce much about the different modalities used yet. Various challenges arose, however, when people shared the setup. Especially when deploying our prototype, we encountered the potential problem of violating users' privacy when people shared a household. Additionally, the audio output and the bright light of the projector could potentially annoy and accidentally wake up the respective partner. Despite reports that participants did not seem bothered by this, these potential issues will need to be considered. Finally, participants voiced a request to stay connected to such memory displays throughout the day to access their schedule and goal summaries. Hence, a comprehensive system including several displays throughout the home or a mobile app component should be considered.

Using memory displays in a home environment has the potential to make data—collected through wearable sensors and retrieved from various online sources—accessible to users. Through our study, we identified a set of relevant content types and feasible display locations, and started exploring different presentation modalities such as visual and audio. Despite its general usefulness ("The prototype helped me to think about the next day and helped to structure it"), more detailed and long-term studies will be needed to investigate display parameters such as display location, further content types, aggregation and modalities, summary granularity, and their effects on memory. Here, several disciplines will need to come into play, such as information retrieval, machine learning, cognitive psychology, and computer visualization.

The prototype we described lays the foundation for a memory display in the form of an alarm clock that overcomes data fragmentation and aggregates various data sources; helps with organizing and remembering daily routines; increases data awareness and hence acts as a step toward positive behavior change; and respects data protection and privacy by locally storing and processing all information in one personal device. As we move to a connected society with technologies pervasively deployed throughout our environment, possibilities arise for memory augmentation. With personal data in combination with displays mounted in the periphery of people's homes, we can invite users to reminisce and reflect on their activities, which has been shown to increase well-being.[5] Information about upcoming events can be used to proactively prepare users for what is to come, which can reduce anxiety, increase anticipation, and promote efficiency. On a similar note, such displays can further be used for knowledge acquisition, such as language learning or news consumption. The design space of memory displays is vast and vaguely explored as of yet. Our work presents first steps toward exploring the displays' capabilities, design parameters, and application space.

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