Rewind: Automatically Reconstructing Everyday Memories with First-Person Perspectives

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Snapping photos or videos on a smartphone makes recording visual memories convenient, but what isn't captured may still be meaningful in retrospect. In this paper, digital mementos are automatically generated for participants using the Rewind system, which assists the recall of location-based minutiae. Rewind is a video-like medium describing people's daily excursions using a sequence of street-level images determined by self-tracked location data. The Rewinds are color-processed to reflect seasonal, time-of-day and weather characteristics. Through two user studies with a combined 40 users, Rewinds were shown to be used as memory artifacts, and are especially meaningful in the many situations when photos or videos are not available. The small cues in Rewinds evoke longer fragments of memory tied to nostalgic routines or significant events, and the sequence of images provide a first-person perspective of remembrance for users. While they are more generic and can possess inaccuracies, Rewinds give people anchors for memories that feel like their own that are used to craft a narrative for that day. Rewind strikes a balance between automatic logging and manually-curated memories by personalizing it in meaningful visuals and consolidating an otherwise overwhelming amount of data.

CCS Concepts: • **Human-centered computing → Empirical studies in ubiquitous and mobile computing**;

Additional Key Words and Phrases: digital memories; location history; travel experiences

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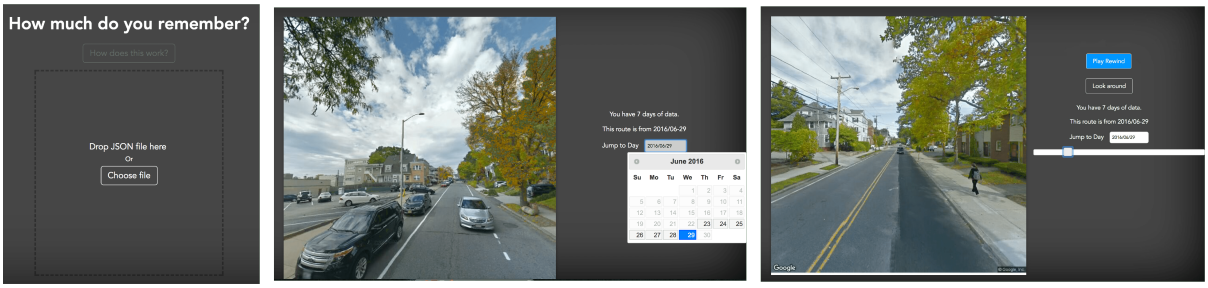


Fig. 1. A walk-through of the Rewind-generating prototype used for the second study. Users can load their location data (left), select a day (middle) and interact with their Rewinds (right).

1 INTRODUCTION

Capturing a memory is a fundamental part of human nature. Not long ago, we chronicled our lives through journals and diaries. This was followed by the point-and-shoot camera, which could be carried around when we expected to obtain visual mementos. Now smartphone cameras are always nearby, ready for an opportunity to capture both the unexpected and the mundane. Evolving along these lines, this paper introduces Rewind, a prototype of automatically-generated digital memories shown in a first-person perspective.

While a camera can explicitly capture a snapshot of a moment, that one snapshot is only a small part of life's many experiences. In fact, treasured memories often happen in transit. Even the most mundane events can be a source of nostalgia: warm aromas of cardamom and cinnamon amidst restless chatter at the local market, sounds of autumn leaves crunching underneath footsteps on a Sunday stroll downtown, droplets of morning dew resting gingerly atop freshly-cut grass on the way to work. A simple photograph lacks this type of context, as on-site experiences captured through lenses may not be as memorable [26] than the quieter en-route experience in hindsight [4].

Our goal is to encapsulate these experiences without burdening the user—without cellphones, body cameras, or microphones that may detract from the moment, or having to decide if a moment is worth remembering. The Rewind system takes users' passively-tracked location data and slices it into routes based on timestamps, after which sequences of street-level images (Figure 1) are stitched together to recreate what a person might have seen at a past point in time. These rapid visual sequences are displayed in an interface that allows users to watch a replay of their routes from a day of their choosing. Simply enabling passive location tracking on one's mobile device is sufficient to later rewind and revisit a moment in the past. Once this becomes reality, how do people interpret these Rewinds, which are both visually generic yet personally specific?

With Rewind, we apply a framework for exploring fundamental questions about the human experience. Normally, it is difficult to ask someone about parts of their past that they do not entirely recall, as they cannot remember exactly what they do not remember. However, we can also investigate what happens when what they remember is not what they are shown.

Using timestamped location data, we investigate whether a contextual digital memory can help surface different experiences, and what value that may have for the users. Perhaps these Rewinds, sequences of images moving back and forth, can help the forgetful recover past experiences or find new meaning in them. This could be done for people who are already tracking their location intentionally (using a smartphone app like Moves or GPSLogger), or for the many people for whom location tracking has been enabled by default (as on many Android phones).

Here, we report on two consecutive user studies with Rewind. In the first user study, we created ten single-trip Rewinds from the two-week tracking period for each participant. We examined if participants were able to identify their trips from their Rewinds and what factors would affect their judgments. Based on participants' feedback, we

created three sets of filters for Rewind to add in temporal variances, which include seasonal, weather and time-of-day effects. In the second study, we used Rewind to generate daily trip artifacts, and conducted in-depth interviews with the participants to understand how Rewinds affected people's memory. In many cases, participants lacked any photos or videos, and Rewinds were the only source of memory media available. The data from the studies was then qualitatively analyzed. This resulted in a set of findings about appropriation, interpretation, typicality, and the medium itself.

The two main contributions of our work are: 1) findings from two user studies that shed light on how memory is mediated by automatically-generated representations of the past, and 2) the design and investigation of the system for generating Rewinds.

2 RELATED WORK

The role of technology in memory has long been studied by HCI researchers, as the presence of lifelogging applications has allowed users to passively track ubiquitous personal data [20]. Prior work has manifested such lifelogging applications in several forms, through automatically recorded photos [31], video-based systems [35], multimedia diaries [10], data visualizations [33], and more. The result of such applications is a detailed output of events, numbers, or behaviors that ultimately result in piecing together a user's habits. Elsden et al. label this particular phenomenon as the *quantified past*, documenting one's history through exact, concise particulars: "It is '8,773 steps', rather than 'around 9,000'" [7]. Elsden et al. enumerate various characteristics representative of a quantified past, such as *passive, third-party recording*, *quantitative and objective measurements*, and that applications should be *removed from the past as remembered*, as representations of personal data in such applications usually deviate from a firsthand experience of what we see, feel, and remember.

By giving users more direct agency to interpret their own data, we expand on these lifelogging characteristics. Street-level images allow us to exploit location history data to create a non-invasive, personally-removed record of a user's whereabouts. While these images themselves are arguably subjective and lack 'quantitative' qualities, the Rewind system supports objectivity. We extract qualitative images from a series of points on a map, strung together by time and location proximity. Lastly, Rewind supports reduction and abstraction. Its use case is not prescriptive; while certain qualities of one's Rewind over time may imply certain behaviors (how often one would walk to a certain coffee shop, or how many times someone would take the same route to the gym), the user is free to abstract their own sense of the record. Specifically, we test the utility of these characteristics in establishing certain affordances for designing lifelogging systems such as Rewind. As such, our contribution is novel in that we actively build on past provocations and suggest alternate ways to interact with lifelogging devices.

In experimental studies using the wearable camera, Microsoft SenseCam [14], researchers have shown that even mundane activities adopted some form of sentimentality over the course of just one week. Moreso, when images were displayed in rapid succession to simulate a stop-motion video, participants noted transitions between images. Single images did not stand alone as sole representatives of an event, rather, it was the sum of the images that revealed insights to the user [22]. In this manner, SenseCam violates some of Elsden's representative characteristics. While wearing a body camera, SenseCam users are made consciously aware that they are recording a first-person perspective of their activities. Likewise, some participants deliberately sought to capture different aesthetic representations of their environment [12]. The variability of user-generated content reflects concepts of agency, as these creative interventions highlight the different affordances of this digital object.

Using such devices to support different, yet specific purposes is not unique to SenseCam. In studying smart journaling practices, Elsden et al. [6] interviewed frequent journalers to see why they chose to document their lives using various forms of lifelogging applications. One user in this study maximized the affordances of two memory recording applications, using each separately for different purposes—either to curate a photo platform for other family members, or to privately journal everyday feelings.

Such themes of agency and personal curation are similarly present in other lifelogging applications. In particular, Gulotta et al. [11] created four low-fidelity systems in order to study digital archival methods. This study revealed that people did not want to remember things that the memory systems would often bring to light. Often this happens when the system does not allow for personal curation or personal contextualization. To what extent, then, do these systems have a right to inform users about their history?

Like Gulotta et al.'s work, we explore these questions of personal agency and curation with Rewind. Various design decisions in the making of Rewind establish the system as a unique curatorial agent by using street-level images. With a low amount of contextual data, Rewind prompts users to construct their own interpretations and responses to how such autobiographical events are portrayed by a third-party system. Like similar lifelogging studies [8, 13], we aim to facilitate a personal connection between Rewind and its users. In doing so, we have created a *visual memento*, defined in previous work by Thudt et al. [33] as "visualizations of personally relevant data for the purpose of reminiscing, and sharing of life experiences." This common goal of providing a new way of reminiscence reinforces the purpose of Rewind, and thus redefines the relationship between the system and its user.

Since Rewind's conception, a similar built-in street view sequence feature has been incorporated into Google Maps Timeline [16], in which a thumbnail shows street-level photos corresponding to its location. Rewind extends this by adding in personal contextual data such as weather and time-of-day filters with the objective of representing more closely what the user saw through their own eyes. Likewise, in Google+ Stories [30], location coordinates are extracted from a user's photos and overlaid on a map. The interactivity of the photo album allows users to simulate the experience of a trip, rather than just simply a series of photographs. Rewind takes this a step further by testing the extreme case where no personal photos are available, and everything is generated purely from timestamped location data that has been collected in the background. We wanted users to feel like Rewinds were their own, all the while using images from public datasets such as Google Street View.

Moreover, we diverge from related SenseCam studies. While we do study mundane day-to-day personal records, the user-generated content is in our case not present within our literal media record. Our study provides a more nuanced perspective of how users may display authorship within these systems—despite not actively recording their experiences, and despite such experiences being filtered through a third party. Rewind is novel in this respect; it exercises a space in digital lifelogging technologies that considers the agency, authority, and ownership in mediating one's memory of an event versus what is automatically recorded by a third-party.

To this end, we provide a response to critiques of lifelogging systems, as some have argued that such an approach is neither necessary nor useful [32]. Though technology gives users the ability to capture their daily activities in extensive detail, users rarely review or reflect on these materials. While lifelogging applications aim to provide a useful tool for remembrance and personal reflection, such moments remain recorded yet untouched. Rather, we incite an alternative use of lifelogging systems: the *qualified past*, rather than the quantified past [7].

3 THE REWIND SYSTEM

The Rewind system is a prototype to engage recollection with only self-tracked location data. Rewind combines user location history data with ready-to-use, location-based metadata that can be easily found online. This includes locative media, such as street-level images, local time, and local season and weather information. By using external sources to retrieve much of this metadata, users only need to input their personal timestamped location logs to use the Rewind system. The software and the online demo is made open source and available at github.com/brownhci/Rewind.

The user's provided geolocation data is used to retrieve sequences of street-level images, which are images captured from the ground (as opposed to aerial images), and stitched together to form the interactive medium, *Rewind*. For Rewind, the street-level images were sourced from Google Maps, i.e. Google Street View, but are also available from Bing StreetSide or OpenStreetCam; Google Street View images were initially chosen as it was

most easily accessible and had broad coverage. However, early prototypes of the Rewind system also revealed a surprising element to the content of the images themselves, as rich, detailed memory representations and personal agency felt within the system contradicted Rewind's passively-recorded, nondescript nature.

Rewind applies color mapping to account for time of day and season in which the sky and ground area are processed separately, individually mapping each pixel to temporal attributes. Animated weather effects account for the weather on the specific days the Rewind is taken from, such as rain or snow. The end result is a smooth visual road trip that can be played like a video clip.

To use Rewind, users first download their location history as a JSON file using Google Takeout, and then upload it to the Rewind web application. After their data is processed, users are able to select a day for which to view a Rewind by using a calendar widget on the sidebar. Once a Rewind loads, it can be played, paused, and scrubbed using a slider. The sidebar also contains a "Look Around" button, which opens a 360° view of the current frame of the Rewind. This works by checking the longitude-latitude values of the current frame of the Rewind, and opens a Street View link that allows users to pan around at will.

3.1 Sequence Creation/Generation

The final prototype of the Rewind system incorporates design changes based on participants' feedback from the first study (see Section 4.2). In this version, the system generates an interactive video-like medium instead of a scrubbing interface that moves back and forward in time, as users expressed difficulty in segmenting Rewinds from one another chronologically. The changes in this version were informed by user feedback from our first user study.

After users load their location logs into Rewind, the system segments the location logs by date and then marks dates that have sufficient location data on a calendar. Once the user selects a date, Rewind finds the first location using a simplified k-means clustering algorithm based on velocity, and determines commute points to the second location by loosely applying the concept of the extracting algorithm proposed by Kirmse et al. [18]. It repeats this process until all data from the selected day are exhausted. The system then sequentially retrieves Google Street View images to fill between each commute point and stitches together the images as frames in a playable clip. Rewind uses a modified version of StreetViewSequence [3], a library which pulls and combines data from Google's Street View Image API with route data from the Google Maps API. The retrieved images are then drawn onto an HTML5 canvas. Since routes are classified based on speed, they only comprise of locations traversed when in transit. Thus, movement indoors is not captured in the Rewinds. All retrieved images have the same pitch and heading values; this makes a Rewind appear as though the user is moving straight down a street from the viewpoint of a driver.

Although there exist more sophisticated (but slow) algorithms that reconstruct images based on time of day and season, Rewind uses a simplified approach of RGB and HSV color space mapping to process these hundreds of images in real-time so the user only has to wait seconds instead of hours. As the street-level images of a given route have been retrieved with the same dimensional parameters and optical orientation, spatial information of each image is largely similar (e.g. the sky normally resides in the upper third of the image, but could occupy more than half of the image at times) (Figure 2). Thus, sky and ground regions could be approximated by generalizing the observed geographical information of the incoming images. For seasonal changes, a range of HSV values is estimated for vegetation classification and those HSV values that fall within the range are adjusted for desired seasonal effects (Figure 3). Similarly, for creating nightly events such as sunset and evening scenes, sky colors are modified using the same technique. Then two linear brightness and saturation filters are applied locally and globally. As an example of creating the evening scene, the incoming street-level images are segmented into three major areas: 1) the approximated sky region, 2) the non-sky region in the approximated sky region, and 3) approximated Ground region. RGB values of each pixel were down-scaled based on the region the pixel is classified in. Some unrealistic artifacts appear (like white foliage on trees in the winter) as a trade-off to using this technique which is not object-aware.

Fig. 2. A sky filter and a land filter are applied respectively to estimated sky region and land region.

Fig. 3. RGB and HSV color mapping was used to create different visual effects to imitate time of day and weather patterns. Foliage in the street-level images are adjusted using the color mapping to show differences in the four seasons.

A NoSQL database populated by historical weather data downloaded from the National Oceanic and Atmospheric Administration weather stations is used for weather look-up. Weather effects are added using an animated precipitation layer over the HTML canvas, and a filter is applied to the sky to adjust for color, using the same color adjustment method used for adjusting for the time of day. Audio effects are also added for certain weather conditions to imitate precipitation sounds.

4 USER STUDIES

Two studies were conducted, with separate research questions. The outcome of the first study informed the system design and research question changes for the second study. Data from both studies are reported together as part of the analysis. The overarching goal of the two user studies was to investigate *if* Rewind is useful for supporting autobiographical memory, *how* it does that, and *how well* it does so.

4.1 First Study Procedure

In this first study, the following questions were answered:

- **Memorability**: Could users remember past trips from watching Rewind?
- **Believability**: Were users satisfied with the techniques that we used to generate their Rewind?
- **Desirability**: Would users like to keep a copy of their Rewind?

Participants were recruited via local offline and online forums to get a diverse sample of the local population. Flyers were distributed at local businesses such as grocery stores and cafes, and online ads were posted on local Craigslist and Reddit communities. The 18 participants were 20–50 years old with diverse occupational backgrounds. Each participant was compensated $30 at the end of the study.

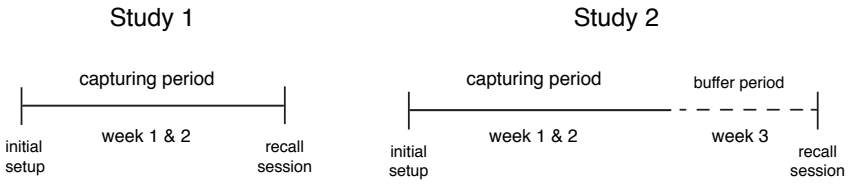


Fig. 4. The timelines for the two studies. The first study focused on the value of the Rewinds, while the second focused on their interpretation of the Rewinds.

We enabled location-tracking services on participants' mobile phones in a setup session, asked them to carry their phones with them at all times for two consecutive weeks to track their locations, and conducted a semi-structured interview with each participant after the two-week tracking period (Figure 4).

At the in-person interview, each participant was shown 10 Rewinds based on their tracked location data. For this first study, we used the first iteration of the Rewind system that intentionally selected a stratified set of trips. Of the 10 trips that were shown, 3 were frequently taken trips, 5 were infrequently taken trips, and the remaining 2 were randomly chosen. Together, Rewind generated 180 single-trip replays composed from 36,000 frames in total. For each Rewind, participants were asked if they could 1) identify the locations and trip taken in the Rewind, 2) if the trip was accurate to their memories, 3) if they would like to keep the Rewinds, and why or why not.

4.2 Design Changes

While our first study protocol confirmed the feasibility of the overall approach, it had two primary constraints. First, street-level images lacked sufficient time-related variations, cornerstone to individual experiences. Many participants expressed a desire to see more temporal differences in the Rewinds. Second, we did not systematically investigate how the Rewinds were interpreted by the participants and what meaning they had, especially when compared to their own digital mementos on smartphones.

To address the first constraint, we created three sets of filters for the Rewinds which were not in the first study. These filters were designed to reflect different seasons, weather, and times of day as described in Section 3. Such enhancements were chosen based on temporal aspects of the environment, and are automatable from timestamps and weather data. Filter features were automatically applied to each Google Street View image based on associated timestamps of the location data.

In addition, the original "scrubbing" feature, which allowed users to rapidly traverse through Rewinds at different points in time, was omitted from the system for the second study. While we initially wanted users to enact personal agency over their own Rewinds with this feature, we decided to implement a simpler interface of sequential frames as users expressed confusion over understanding the chronological order of their Rewinds. To still allow for personal agency in viewing the locations, we instead implemented the "Look Around" feature that allowed participants to navigate a 360 degree view after pausing a frame.

The second study posed new research questions aimed to better understand what the Rewinds meant to the users. And to identify how Rewind related to the media in users' smartphones, we changed the system to accommodate a fairer comparison. Instead of singling out one trip, we changed Rewind to reflect all trips taken on a day to make a fair comparison with digital mementos captured on smartphones of the same day. This is in contrast to the Rewinds used in the first study, where routes were selected based on how many interesting places existed along the way between two endpoints.

4.3 Second Study Procedure

In the second study, we focus on *how* Rewind supports the process of remembering. The study was designed to address the following questions:

- How do people remember a day after watching a Rewind? How does Rewind connect them to their past?
- How well can they remember compared to their intentionally captured photos? What aspects of the Rewind helped them remember?
- How do they value Rewind? What aspects of the Rewind do they or do they not like or find useful?

25 participants were recruited using the same method as in the first study. Three participants withdrew from the study partway, which left 22 participants (10 female, 12 male), aged 18 to 66 (M=29.6, SD=13.8) with occupations including, but not limited to, data analyst, deli associate, ticket manager, student, mover, and retired senior. Like our first study, each participant was compensated $30 at the end of study completion.

Figure 4 shows the timeline of the second study. Like the first study, there was an initial setup session, two weeks of location capture, and a 30–45 minute audio-recorded recall session, all described in detail below. In addition, we added a one-week buffer period to account for potential recency biases [25].

Capturing. Participants first came to the lab for an *initial setup* session, in which location tracking was enabled on their mobile phones. Those with Android devices used Google's built-in location reporting services for tracking, while those with iPhones downloaded the Google+ app to use the same functionality. Participants were asked to keep their phones charged and on their person as much as possible for two consecutive weeks, which we refer to as the *capturing period*. To minimize subject-expectancy bias, participants were informed that they *may* be asked to review pictures and videos taken on their phones in the next session. Participants were then invited back to the lab for a *recall session* after a one-week *buffer period* following the capturing period. The buffer was added to reduce recency effects [25], and to provide time for naturally forgetting.

Recall. Participants downloaded a copy of their location data from the two-week capturing period, which were used to generate Rewinds for all the trips taken on a randomly selected day. Each Rewind was a compilation of up to 700 frames. Like related studies [17], we excluded weekends and common national holidays as these may contain atypical events. Focusing on weekdays allowed us to control for the high variability of such events, in order to localize the effects and qualities of Rewind itself on a more constant, constrained dataset.

We conducted a semi-structured interview with the participants, comparing Rewinds to photos that they had captured using their device[1]. Researchers did not personally view participants' photos, as recommended by our institutional human subjects review office. Rather, participants were instructed to simply describe the photos in question and whether they remembered it. There were three conditions: 1) unaided organic memory (baseline), 2) using the Rewind system, and 3) using photos that participants kept on their smartphones on the selected day. The Rewind and photo conditions were counterbalanced to control for ordering effects. In each condition, participants were asked to recall all the events that they could remember on that day.

[1]We originally intended to compare Rewind with both photos and videos, but none of the participants actually took videos on their own volition during the two week study period.

A set of questions were asked for each event, based on the Day Reconstruction Method (DRM) probes proposed by Le et al. [19]. Participants were prompted to recall where and when an event happened, their thoughts during the event, the context of the event, their emotions, and how salient the event was overall.

During the Rewind condition, participants were asked to think aloud, and to describe the parts of the Rewind that triggered their memories. If the photo condition came first, participants answered if they would be able to remember the same events they reported during the photo condition after watching Rewinds, and vice versa. During the photo condition, participants also reported the amount of media, including photos, screenshots and videos that they captured on their phones. Participants only took a total of 39 photos and screenshots on their phones; 10 participants did not take any photos during the two weeks. No videos were captured for the workdays we randomly selected.

At the end of the recall session, each participant was provided with a questionnaire to rate Rewinds using a 5-point Likert scale, 1="very bad" or "very unlikely", 5="very well" or "very likely" depending on the questions:

- Rate the qualities of computer vision effects on season, weather and times-of-the-day
- How helpful Rewinds were for remembering the day in question
- How well do they think the trips depicted in the watched Rewinds are coherent to their memory
- How likely they would use Rewind again for reminiscence purposes

4.4 Analysis

We conducted a thematic analysis [2] of the collected interviews from both user studies. To maintain external validity, one co-author was the "analyst", who did not participate in the user studies or design of the system. The analyst coded the transcripts for qualitative themes using RQDA [15], a tool that supports textual analysis for manually creating, categorizing and connecting codes. The analyst began with the original design themes, coding the data and adding new themes and sub-themes as new patterns emerged. As the analysis approached theoretical saturation, the other authors met with the analyst to review the categories and codes. This review was conducted over multiple sessions until all members had consensus over the codes and their associated categories. As a result of this review, the analyst revised the reported findings to improve the trustworthiness and transferability of the analysis [21, Chapter 11]. Our completed analysis was comprised of 15 categories, which included 83 codes in total.

The primary analytic goal was to understand if and how Rewind accomplished its design goals to be believable, desirable, memorable, and to represent typicality. These four concepts were used as initial categories in the coding process. The analyst also identified recurrent interactions and perspectives of Rewind that emerged as thematic

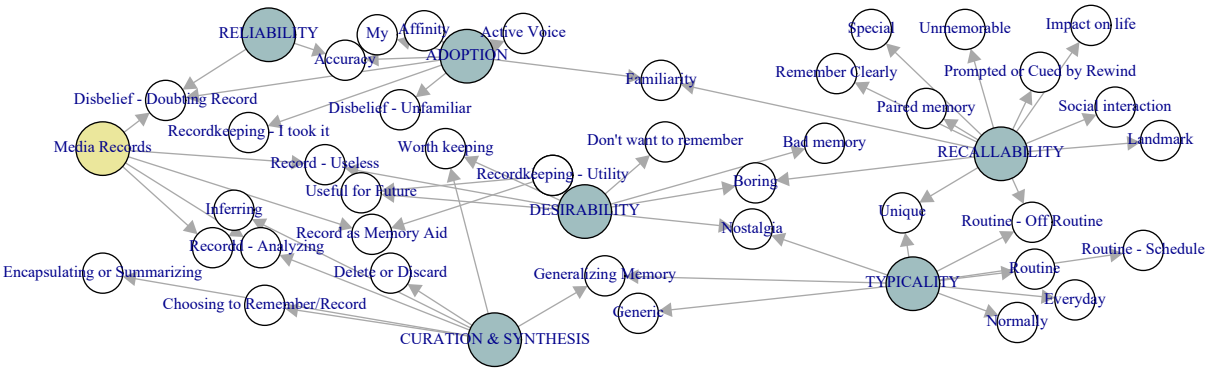


Fig. 5. This concept map shows an excerpt of the thematic analysis. Smaller, interconnected codes stem from major thematic concepts, rendered as larger circles: Adoption, Curation and Synthesis, Desirability, Recallability, Reliability, and Typicality.

categories themselves. This process led to revisiting the original design themes as we found more nuanced definitions of such topics. For example, we found slight distinctions when users treated Rewinds as representations of first-person perspectives than when the user conceived their Rewind as an objective truth. That led us to split Believability into two codes: Adoption and Reliability as two orthogonal concepts emerged from within the dataset itself. Memorability was unpacked into the triggering of episodic memories by cues in Rewind, versus Rewinds as memory media records. The findings and discussion below collect our quantitative results together with qualitative analysis from both user studies.

5 REWIND AS A MEMORY MEDIA RECORD

Overall, our findings show that Rewind's artificial and automatic compilation succeeds as a digital memory artifact. As in previous work [10], digital artifacts are used as personal records of one's life. In the same vein, Rewind represents recordings of the user's past through media, and is experienced by them in the same way as personal photos and videos.

Comparing the number of events recalled by each participant, we found that on average, both Rewinds (M=1.18, SD=1.43) and deliberately captured photos (M=0.82, SD=0.91) helped participants recall more events than the baseline condition, using only their organic memory (M=0.45, SD=0.60) on a randomly chosen weekday. A non-parametric Wilcoxon signed-rank test with continuity correction (used because the numbers of recalled events did not follow normal distribution) showed that the difference between Rewind and organic memory is statistically significant ($Z = 2.037, p < 0.05$), yet insignificant between Rewind and photos, and insignificant between photos and organic memory. However, despite insignificant quantitative differences of recall between Rewind and photos, we observe a difference in how users interpret various forms of memory media as noted in Section 6.2.

This suggests that Rewind is useful as a memory artifact when photos were not taken during the day being recalled, as participants only relied on their organic memory. In fact, in the second study, there were only 39 photos taken in total by the 22 participants during the two week study period. 10 participants did not take photos at all. Therefore, there is a substantial amount of time when Rewinds may serve as the sole source of memory media in comparison to their own memory.

5.1 Triggering Episodic Memories

Like any memory artifact, Rewinds prompted people to recall specific temporal events [34]. These mechanisms for recall work alongside expected ways that memories come to mind; interviewees briefly mention how certain types of memories are easier to recall: familiar, unique events, impactful experiences, the subconscious, memories in the front of mind. Often in Rewind, these triggers are location or temporally based.

In the following comment by a participant, an image of a bus stop in a Rewind triggers a reminder of a past stressful event,

> "The bus stop I was standing at was right here (points to Rewind), across the street from there on this side. Yeah that's where I was standing at, right there, poor thing—right on that circular glass, he smashed into that. It was one of those little brown domestic birds. And nobody really had any sympathy for it, and he was on the pavement writhing in pain, and his neck seemed to be stuck backwards... I know if those images weren't put in front of me, I wouldn't have remembered that poor bird." —P8

In contrast, P4 describes a positive memory as evoked by visuals in their Rewind,

> "When I see the Kennedy Plaza picture, I think of 7-Eleven there and there is always a funny homeless guy and he stands outside and he does rap songs, and you give him a dollar and he would rap a song for you." —P4

In a less direct manner, we observed that the ambience of Rewind's visuals can trigger memories as well. P21 recalled their partner taking them to a different city,

> "So we're on the road there now, we're playing some old music from long ago, feeling nostalgic, and it was beautiful, taking the back highway, not the main freeway, to get there. The windows were down, and now we're in New Haven. Now we're on the bus to get back to Rhode Island." —P21

When asked how they remembered the windows were down, P21 stated it was the "greenness" of the scenery that brought their memories of being in their partner's car and playing music together. These direct and indirect triggers may seem conventional, but we find it notable that Rewinds are artificial reconstructions, algorithmically reframed as first-person perspectives. Additionally, they are necessarily imprecise; the location data cannot report what the user was looking at or doing at that moment. Thus, the cues that users rely on are equally indirect.

> "I mean I didn't remember that I got gas until I saw the image that showed it, because I wouldn't particularly remember that well." —P12

> "This right here (points to Rewind), reminds me of one day, I had a day off work, and I was riding my bike and there was a sign that said "Now Hiring," and I went in there, and I get emails now, and I'm glad I did that because I found out about hiring and employment resources... So I remember that when I see that [in the video], when I go up here." —P8

5.2 Abstracting the Everyday

People's routes often repeat over their daily schedules; some routes more typical than others. We found that typicality was a major facet of the user's recall and experience of Rewind. Remembering factual information along the routes, such as landmarks and building names, seemed to increase with trip frequency. This means that participants were more likely to recall fact-based characteristics of landmarks and architecture due to the recurring occurrences of the same environment, as suggested by past psychology research that unintentional remembrance of frequently presented information is possible [1]. The first study further substantiated this as 76% of participants who successfully recalled location information were from their most frequently taken routes, as opposed to 36% recall from their least frequently taken routes ($\chi^2(1, N = 128) = 14.458, p < .01$).

A single cue from Rewind can evoke the memory of typical trips, activities, and routes. These appear closely connected to the type of data that Rewind is based on. We observe that these memories themselves are recollected as more abstract and impressionistic than the images in Rewind themselves.

> "This is the bridge I have to cross everyday to get to work, because most of the days I drive my bike to work. Even when I drive, I have to cross the same bridge. I think it's called the Point Street Bridge that goes over the 95. So I think that could be a landmark, because as soon as I see the 95 I knew where I was." —P9

Such memories of routes, trips, commutes, and other typical paths are tied to a consistent location and periodic time, both key features of Rewind's location data. Although, for typicality, these two features are not always tied together. One exceptional case shows typicality that is connected to time, but less strictly to location. P20 was cued to recall a personal ritual, "the street view of me biking made me remember like what biking is like in the evening, like it's very calming, I sort of like to do it to like, de-stress a little bit, and exercising before going to sleep, because it helps me sleep." Rituals are not strongly tied to a trip or path, but with an activity. We found Pastalan and Barnes' definition [27] useful here. These are unique and personal activities, like putting on makeup or making tea. These are personalized, repeated, and—different than our definition of typical trips—not necessarily tied to a place. In the case of P20, it is tied to a time of day.

Despite being the record of a specific time and place, Rewinds can cue abstract memories of a routine. These memories spread beyond the single instance. P15's Rewind was the first day of volleyball practice, but the recollected memory encompasses all of the trips to practice from then on. In support of the idea that the typical memory is different than the memory of the day, P15 described two different valences. One, the first day of volleyball practice was one of excitement. Two, the feeling behind all volleyball practices meshed together was more neutral.

Two patterns emerged while analyzing typicality in the thematic analysis. First, Rewind cues participants to remember a routine or ritual. A landmark from a single day evokes the memory of an entire route over the span of a month. Second, the recall direction can be reversed; typical routines act as the backdrop for understanding and interpreting Rewinds. These behaviors emerged from Rewind without any intentional functionality designed to represent typicality.

6 INTERPRETING REWINDS

Details presented in the image processing effects also helped participants understand their Rewinds. 73% of participants believed that the temporal-based image manipulation applied to Rewinds helped them jog their memories to recall the day. P21 noted that although they knew that the image in the Rewind wasn't specific to the day they were trying to remember, the effect of the color filter, which made the foliage greener, helped them remember where the image was located, "I know the Google Maps data isn't for that specific day, but it's very green around there." Participants also made inferences from the manner in which Rewinds were presented; P7 noted that "[The Rewind] stopped for a second at the library, and that reminds me that that day I stopped in the library for a little bit because I was sitting down with the protein bar I had for lunch." Thus, inferences were made not only from the locations they recognized, but the presentation of the Rewinds as well.

This sentiment is observed in P7's evaluation of the Rewind system. After reviewing their Rewind, P7 rehearses what they had done in sequence: "Yeah, and then [I went] down Angell, and then down Wayland, and then back home... It's excellent, yeah." P7's appraisal more generally reflects the overall pattern of how users' affinity was related to how closely the Rewinds reflected their own personal narrative.

6.1 Reframing Users' Perspectives

Participants understood that Rewinds were one perspective of the past—a sort of ground-level point of view—though it did not always match their own perspective. However, even when the images in the Rewinds did not match a participant's perspective, they were still successful in prompting a recollection of memory. We see this in P31's remarks, "Central Falls is *familiar*. The video makes Central Falls look a lot nicer than it actually is—*I don't see the world like that*."

Furthermore, after choosing to focus on specific details, participants scrutinized them. They analyzed the Rewind and its surroundings. They inspected the signs, landmarks, pathways, and raised questions about the weather and time. Their goal was to make sense of the record. P16 recognized a store, noting that it looked different in the Rewind than how they usually view it in real life,

> "You know when I saw the CVS, it just looks different here when I look at it than when I walk across it... I think the perception of how things look when we walk, or when we drive, versus how it looks here, it definitely looks different." —P16

In these cases, participants were keen to point out the differences between Rewind and their memory, but they then still recalled particular episodes or places.

6.2 Relying on Rewind to Infer the Past

Users applied their memory of past routines to figure out what they were doing on a particular day. Some Rewinds posed a challenge for users. They are cued to recall a familiar route or trip, but they also encounter out-of-routine irregularities. An out of place image could be a red herring or a forgotten detour from a routine. Can the users piece together what happened?

In the second study where we asked about Rewind's connection to their memories, 17/22 participants (77%) thought Rewind was coherent to their memories and 16/22 participants (73%) deemed Rewind useful for helping them remember the days being probed for the interview 6. More specifically, the majority of the participants

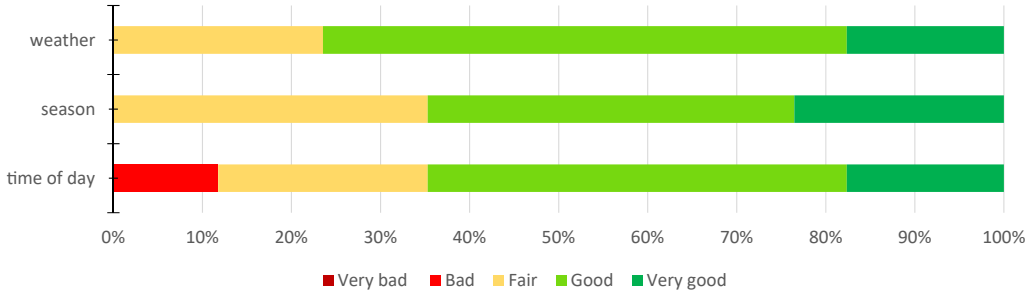


Fig. 6. The ratings given by participants for the image manipulations to show weather, season, and time of day effects.

also indicated that the weather (86%) reflected in the Rewind was a 'good' or 'very good' representation of their memories, followed by times of the day (78%), and seasons (73%) as seen in Figure 6.

Through this, the user feels that they are able to rely on this record as a representation of their past. However, in some scenarios, inaccuracies in the street-level images account for memory uncertainties. Figure 6 shows that while most image manipulation techniques were *good* or *very good*, participants noted poor reproductions for what they recalled. In this case, the user uses the Rewind as an objective anchor to verify their own memories.

> "First I saw the weather, I was very confused on what day it is, because I had the wrong day at first, like the weather was a big trigger for me that I probably had the day wrong." —P11

In the above comment, P11 internalizes the visual depictions of their Rewind as the ground truth. We see that the participant probes for different memories based on what they have observed in the Rewind, adopting their interpretation of the Rewind as fact. Similarly, P17 defers their memory account under the assumption that Rewind was more 'reliable.' In this case, P17 initially recalls a different memory according to ambiguous details shown in the Rewind, "Because we went a similar route, um, to get there. That's what made me think that [the Rewind was from that day], you know because it wasn't a four-lane or a six-lane highway." They asserted that this was correct until the Photo condition, where the participant discovered that their pictures had instead reflected a different day—reflecting that their memory as prompted from the Rewind was incorrect.

On the other hand, while Rewind may also depict unfamiliar environments, participants are reluctant to discard these location cues as they often prompt further analysis.

> "I did not go on a boat, so I don't know where that is... Oh yeah, I walked to work, yeah, that's my work... that's where I work... Where did I go? Why did I go up here? Why did I go there on a Tuesday? I came up here for some reason... That's really weird. This is wild. I don't remember why I went up here, I'm trying to think of the reasons I come up here. You know what, actually, I might have come up here for a coffee. I'm going to look around." —P1

In this quote, unfamiliar location cues in the Rewind cause P1 to elicit feelings of doubt surrounding their activities during that particular day. In such a case, the participant appropriates and reconsiders their own memory to align with what is represented in the Rewind.

6.3 Negotiating between the User and Their Rewind

When shown a Rewind, participants depended on details in the images to make inferences about the day they were actually remembering, where the memory was located, the mode of transportation taken, and the events that occurred. Often these details were visual cues, but they also relied on the weather effects to help them remember. The visual cues that participants focused on to help them understand a Rewind consisted of the buildings, roads, signs (street names, names of restaurants), and other location details. Participants dug into the Rewinds, making

use of the "look around" feature that let them pan around the Rewind. Participants often used this feature when the Rewind featured an ambiguous location ("That last chunk, I'm like a little confused of where [I am]... mind if I look around?" —P12). Users would also use the feature to confirm where a location shown was; P1 offered, "You know what, actually, I might have come up here for a coffee. I'm going to look around."

Though it was not outright said, users who expressed doubt about the media record would spend extra time investigating, postulating, and solving the mystery of an unfamiliar Rewind. It is as if Rewind's objectivity featured heavily in their sense of affinity with the media record. Consider how P1 claims that they were "shook" by the unfamiliar memory:

> "Was I on duty? Because it looks like I went to the hospital. Was that a Tuesday? Where did I go... I don't remember any of that. That's wild... two weeks ago. No, that was a Friday? I'm shook. I don't remember any of that, I don't remember driving anywhere. That's so strange." —P1

Their reaction is not instant rejection, instead, P1 interprets the Rewind as a mystery to be solved. In doing so, participants not only used location cues to understand where they were, but combined them with their known usual routines and behaviors to make inferences about the day they were presented with. We see this exhibited in P16's postulation:

> "*I don't know* if this is how my every day commute looks, or if I went somewhere that day and I don't remember because sometimes on my way home I can like run an errand or go to the grocery store, but I don't, *based on this I can't tell if this is my normal (interrupted).*" —P16

Likewise, P3 made inferences about what location the Rewind was showing based on their routine, "This is probably the East Side, I'm always hanging around here. I'm not sure what this is... Oh, this is Thayer Street! I must have been here. I can't remember what I was doing, though. Oh, I remember." In turn, when trying to remember what they were doing on a specific street shown in the Rewind, P16 stated "I think I must have parked here. Because when I come here, I park in different locations."

7 ADOPTING IMAGES BY STRANGERS FROM ANOTHER TIME AS ONE'S OWN

The original street-level photos used in Rewind were typically captured long before the two week study period by strangers, yet participants discussed them using language as if they showed places they had been, and as if they had recently happened, reflecting their feelings of authorship over their Rewinds. There are distinguishing aspects to a user's experience of Rewinds that reveal a close connection to the periodic nature of daily data logs as well as the affordances of location-based data—detailed discussions of landmarks, transportation, routes, and trips.

We observed that users appropriated Rewinds to be consistent with their own personal narratives. In the second study, 21 participants (96%) described their Rewind experiences as first-person representations of their past, rather than externally observed activities. Participants often used possessive pronouns and an active voice when describing their Rewind, implanting themselves in the environment ("We're on the road there now." [P21]). These demonstrations of authorship and self-presence are seen when participants refer to scenes in the Rewind as *theirs*: "*my* building" [P9], "*my* office" [P3], "*my* work" [P1]. Another instance of this is seen when P20 refers to a particular point in the Rewind as "the streetview of *me* biking." The degree to which participants feel a sense of embodiment within their Rewind depends on reliability, familiarity, and affinity.

7.1 Choosing What to Remember

Our interviews uncovered a set of interpretive behaviors with Rewind that we classify as choice and inferential analysis. Participants were selective about choosing what to remember, and what to attend to in the record in order to understand the Rewinds presented to them. So while participants would treat each Rewind as one complete episode, they were actively curating the memories triggered by the Rewind they saw.

The Rewind system does not give options for users to curate the Rewinds or details in the Rewinds presented to them. However, participants discarded details they considered irrelevant, even as they used Rewind. Although Rewind has no delete feature, we observed users speaking as if to dismiss unfamiliar or irrelevant sights. When trying to understand where a certain route in the Rewind was located, P17 stated that "that doesn't tell me anything over there. That's not gonna tell me anything." When trying to make sense of the differing weather of the street-level images, P17 decided that the day was sunny rather than cloudy, "Okay I'm gonna say it was sunny. That's what I'm gonna say." These verbal expressions show how users select and dismiss different aspects of the Rewind media record, wrestling with the familiarity and reliability of the location data or its perceived reliability.

Participants were also selective in the types of memories they chose or wanted to remember. In the first study, P33 noted that they "didn't need any more memories of work." P18 stated that "If I forget going to Braintree, it's really not a big deal, but if I forget a day that really stood out to me, that was important to me, that would bother me more." This relates to the desirability of the record. This action of picking and choosing over the media record may have greater relevance in Rewind and similar collections due to the lack of human authorship at the time of creation.

As users interacted with their Rewinds, they often remarked on the familiarity of certain landmarks. This is an aspect of appropriation and adoption, as users interpret familiarity to signify their personal relationship with the location cues in the Rewind.

> "That's the way I take to work every day! (laughs) That's really cool. This is the bridge I have to cross everyday to get to work... as soon as I see the 95 I knew where I was." —P9

Note how the preceding quote reflects feelings of intimacy with the surrounding area. P9 employs first-person pronouns and an active voice as if they were physically placed in the Rewind to resonate their frequent involvement with the landmark—thus leading to an overall impression of ownership over their Rewind.

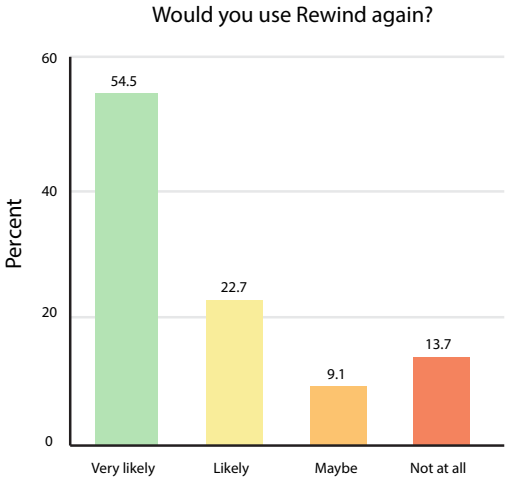
Participants found some Rewinds particularly worth keeping because these Rewinds reminded them of specific evocative experiences. P31 found one of his Rewinds worth keeping because it is "nostalgic, it reminds me of where I grew up." But as a memory artifact, it was unsurprising that participants also did not want to keep negative memories, "I don't want to remind myself that I go to Massachusetts to buy tobacco." —P28

7.2 The Personal Value of a Rewind

Associated with users' sense of affinity is the fact that Rewind is based on their own location data. When participants were asked in the second study if they would like to use Rewind, 19/22 participants (86%) indicated that it is possible for them to use Rewind again, with likelihood ranging from very likely (55%) to likely (23%) and maybe (9%) (Figure 7). Of the 19 participants, 17 of them explicitly explained the reasons behind their choices. These reasons mainly fall into three categories: they believe that Rewind could help them 1) remember a day, and the little things forgotten each day (5/17), 2) reflect on meaningful days and important trips with the tendency to share Rewinds with friends (5/17), and 3) remember specific moments and stories that would not be recalled otherwise (3/17). Others praised the convenience with which they could still remember and reminisce without manually taking pictures (1/17), the new perspective brought to their lives and the ability for them to reflect on daily choices (1/17), and the possibility of using Rewind in legal systems and with people suffering from dementia (1/17).

To this end, users made remarks that demonstrated a sense of affinity between themselves and the capturing style or view of Rewind. For example, P15 remarked, "The Rewind is as accurate as I would be, so it was at my house, to the BDW [Brown Design Workshop], to back home, to practice, to back home." It is not just the accuracy of Rewind that P15 is commenting on, but that the style of accuracy matches their own.

One participant, P8, was highly engaged with the Rewind, recalling many events that happened in a day in significant detail. Because the participant's memory had been impaired due to a past drug addiction, Rewind was especially meaningful in demonstrating an objective recount of their day. When asked how they felt about being able to recall memories associated with their Rewind, they stated,



Why would you like to use Rewind again?

For remembering forgotten details	5/17
For reflecting on meaningful experiences, sharing with friends	5/17
For remembering specific moments and stories	3/17
For convenience	1/17
For reflecting on day-to-day choices	1/17
For use in legal systems and memory deficits (as a practical aid)	1/17

Fig. 7. Rewind affinity participant ratings in percentages (N=22); qualitative participant suggestions (N=17).

> "It's a big deal... because I was smoking crack cocaine for a long time, and I would be unconscious a lot, walking around, sometimes I'd be sleepwalking in the streets. And I'd be homeless, sometimes I was just sitting in basements for a month at a time sometimes, just unconscious about life. I'd just sit in a room or a small space hiding from the world, getting high, for long periods of time. My mind didn't have the ability to function the way a normal one would, and I feel that the way I've been able to come out—I've been clean for 8 months now, and for me to remember something like that [in the Rewind], that's a real privilege for me, and I'm happy about that, because it shows I get a second chance at life, to live again." —P8

8 DISCUSSION

While our system captures locational images from a detached, street-level perspective, we discover that simply seeing familiar events was enough to trigger users' adoption and authorship of the Rewind. Based on users' recognition of the landmarks within their Rewind, users developed a first-person relationship with the system. Though this media was automatically generated, and delivered unedited, users were still able to develop an intimate relationship with the Rewind, and the system was successful in helping probe users' memories. The juxtaposition of the indiscriminating nature of street-level images with user's own relationships with their Rewind may allude to the idea that such scenes and memories can both be recycled, in which case, general and non-specific imagery is appropriated as an intimate memory. The utility of Rewind speaks to the possibility of further design scenarios, such as memory aids for those suffering from dementia. In practice, reminiscence work has been extensively used in therapeutic stances with dementia patients, providing strengthened narrative identity [23]. Another example of this is the Google BikeAround [9], a stationary biking system that utilizes Google Maps images to aid memory for dementia patients. To this extent, Rewind may be utilized in order to build a stronger sense of one's day-to-day narrative, especially critical for those with dementia.

Considering these aspects of Rewinds, we see the nature of the media record prompting a style of remembrance. For Rewind, the presentation of the media record affords attention to locality, a first-person perspective (even if a little disjointed), and sequentiality. These themes lend support to the facilitation of familiarity through image manipulation based on time of day, weather, and season, to fulfill the explicit design goal of creating a believable experience. In such a case, the ethical implications of such systems must be carefully considered due to the relativity

of recorded media, and to a much larger extent, recorded history. We stress that the user should have agency over their data, and what narrative their data suggests about them. While Rewind does not offer an exact, objective account of one's history, yet it offers a more nuanced compromise between an impartial third-person recording and one's anecdotal memory of an event.

To what extent does a passively-tracking lifelogging system such as Rewind, then, have the right to inform or assume certain characteristics about a user? We contend that there may be a mediating point between the user's computer and their data, as the user needs to consent to the information that the computer assumes in order to avoid creating a false or unwanted narrative. Several participants in our study alluded to the necessity of a curatorial process in reviewing past memories, as there was an explicit desire to exclude certain memories. Yet, to another degree, we must consider that media can be manipulated with different self-motivated goals that may deviate from the ground truth.

8.1 Implications for Designing Memory Records from Lifelogging

Our findings suggest that lifelogging technologies may fall into two use categories, as they can either be interpreted as a representative of the objective truth or act as a curatorial object, in which the user selectively displays which events they want to remember in detail. What role should a lifelogging application play in filtering or not filtering out undesired content? In either case, we advocate that lifelogging technologies should be explicit about their approach with its affordances and mental model. In an age where data privacy is of utmost importance, systems need to inform the user of how they convey data, in newsfeeds, timelines, and more as different manifestations of personal data can convey divergent narratives.

Like Sellen and Whittaker [32], we concur that while we as users have the capability to record a total capture of personal information, lifelogging technologies become less useful without direction. Our findings on typicality and memory abstraction may be extended to provide more insight on determining what events people do or do not wish to discard. Currently, we see this adopted in a feature of Google Photos [29], which asks the user if they want to intervene and archive select screenshots or pictures. Perhaps such a system can impart the same procedure on photos based on an analysis of their content, purpose, and time when taken.

Specifically, we suggest that lifelogging and archival technologies possess greater utility when the user is able to integrate additional information or media to their digital record, especially enabling the formation of sequential memories. This theme is emergent throughout much of our study, as though participants internalized the Rewind as an objective memory record of their past locations, several details are left out. For example, P8 describes an important sentiment regarding an unfamiliar location, "I needed to be polite as I possibly could, because I was in a place I had never been and I seemed to be the only black person in the whole city." In such a case, this particular sentiment cannot be physically captured with our current system, arising only after the participant establishes a relationship with their Rewind by engaging in discussion about their record.

Crucial to Rewind is its first-person evaluation process, as in other qualitative inquiry techniques such as auto-confrontation [24] and stimulated recall [5], where participants examine self-reflective material such as videos of themselves performing a certain action or interaction with others. Acknowledging a first-person perspective in reviewing these materials is crucial to an individual's privacy. Without doing so, a third-party gaze may result in serious ethical implications: an advertising company may use this information to influence where an individual goes, or an authority may falsify event details in Rewinds to convince a person they were someplace that they were not.

In this respect, Rewind serves as a tool to exercise the digital and ethical space between how our personal histories are recorded and remembered. As we age, so do the technologies we use; how, then, do we make sense of our own extensive digital archives? Furthermore, other ethical implications about data privacy must be considered when accounting for the media format of Rewind. With concerns of false memories and compromised data, how do users know that their data is truly theirs? This responsibility adds another role to personal informatics tools—enough transparency to show the provenance of the derived digital memories from the data. Overall, the ability of such

tools to affect our very humanity reflect a larger necessity for a more transparent relationship between the user and their digital record.

8.2 Limitations

There are limitations to what Rewind can do, as a prototype of a medium where only location data is used, and in which primarily outdoor street-level images are retrieved. A person's day is therefore only represented by the time they spent outside and the commutes taken, eliminating a specific set of events and memory cues. Similarly, Rewind only maps physical location, eliminating a host of other facets such as travel partners, online activity, and more; these attributes, if included, would impact the types of abstracted memories recalled and genericized by participants.

The study design itself also had limitations; we did not map our participants' relationship to their own media before conducting our research. The number of photos and videos they took varied significantly, with some people not taking any at all. However, we purposely did not give participants instructions to take a certain number of photos or videos in order to prompt a more naturalistic study.

In addition, Rewind also presents memories as "daily" episodes; this format prompted participants to treat each Rewind as a single comprehensive, self-contained episode. However, segmenting memories by day may not be the most accurate representation of memories. There is room for future study of how presenting in a different temporal format (e.g., aggregating all routes from a week in a single Rewind) would affect a person's recall.

9 CONCLUSION

Someday, a routine becomes a memory. Photographs are memories we choose to remember, but moments not captured on camera may be lost; as we noticed for many people, personally-captured videos are nonexistent and photos are rare if any were taken at all. In Marcel Proust's *Remembrance of Things Past*, the taste of a Madeleine cookie triggers nostalgia for his childhood memory of eating afternoon cakes at his aunt's house [28]. Like in Rewinds, small visual cues can be a reminder of a once-ordinary routine, but at other times can surface specific memorable events. Even these digital momentos that are automatically created from passively-collected location data can reconstruct rich experiences that people adopt as their own, like a forgotten souvenir brought from the past.

There was a tension between the precision of Rewind as an algorithm-driven system and its fallibility due to technological limitations. Memories are not exact either, and can still be triggered with specific yet incorrect familiar cues. But when the Rewinds did not match the personal memory, people investigated both in their minds and in the Rewinds, to eventually craft a compatible narrative. Therefore, as a form of memory media that is trusted as reliable, the visual mementos ought to always be tied back to the originating data in a transparent way. In doing so, there is potential for using personal informatics data as more than an informational log, but also an expressive media that can be more evocative than its original form. As Zhang et al. discovered about time capsules [36], "*by recording ordinary moments today, one can make the present a "present" for the future.*"

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