PhotoClock: Reliving Memories in Digital Photos as the Clock Ticks in the Present Moment

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Figure 1: Images of Ashley's PhotoClock app in field. Having a larger size widget on her home page as a subtle trigger for reflection, Ashley often entered the app to revisit her digital photos taken around the same time of the day. Sometimes during her work in a cafe, she would put her phone beside the laptop as a desktop companion. Photos taken in Vancouver, Seattle, and Iran often surfaced, prompting her to reflect on memories of these different places.

ABSTRACT

As digital photos grow exponentially, people need new approaches to engage with their photos over time. We describe our study of *PhotoClock*, a mobile application that leverages the temporal metadata embedded in digital photos to encourage contemplation of memories bound up in one's photo archive. PhotoClock uses the clock-time of the present moment to re-present one's photos taken around that same time of the day in the past. As time ticks away relentlessly, PhotoClock highlights the ephemeral and ongoing quality of time. We conducted the field study with 12 participants over 8 weeks. Our goals are: (i) to investigate the reflective potential of clock-time as an alternative design approach for supporting memory-oriented photo interaction, and (ii) to explore conceptual propositions related to slowness and temporality. Findings revealed that PhotoClock generated diverse and reflective experiences on participants' life stories. We conclude with implications and opportunities for future HCI and design research.

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CCS CONCEPTS

• **Human-centered computing** → Interaction design process and methods.

KEYWORDS

digital photos, slow technology, interaction design, clock time, memories

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1 INTRODUCTION

Photographs have long existed as a resource to support people's practices of documenting their life experiences, self-reflection, social connection and contemplation of the future [16]. Today, people's photographic practices are highly mediated by digital devices and services where the convergence of social, mobile, and cloud computing has enabled people to create personal digital photo archives at scales larger than ever before. As an example, people

took roughly 1.72 trillion digital photos globally in 2022, and 92.5% of the photos were taken with smartphones [10].

These vast and still growing personal archives of digital photos pose new challenges for the Human-Computer Interaction (HCI) and design communities. As digital photo archives grow larger, they increasingly become formless and placeless, lacking the material presence that might invite people to notice and engage with their archive as an everyday resource [61, 68, 82]. This tension can create barriers for people to gauge how big their archive is and, consequently, revisit experiences, histories, and impressions captured within them [68, 89]. Recent research has shown that the adoption of smartphones and low-cost cloud storage over the past decade has catalyzed a hyper accelerated growth of personal photo archives, further amplifying already existing tensions [4]. These changes also create new opportunities for people to reflect on memories within their photo archives which now capture considerable breadth and depth of life experiences over various years.

Yet, there is limited knowledge on what techniques, strategies, and concepts could help guide design research to better support reflective experiences with large photo archives. Growing work in the HCI and design communities has argued there is a need to develop alternative design approaches that support a diverse range of open-ended experiences of reflection, interpretation, and slowness when revisiting digital photo archives (e.g., [12, 22, 42, 62, 85]). Additionally, as technology becomes further integrated and present within everyday life, researchers have argued it is critical to "investigate what it means to design a relationship with a computational thing that will last and develop over time – in effect, an object whose form is fundamentally constituted by its temporal manifestation" [55:11]. However, examples illustrating how such engagements with personal photo archives can be mediated through the creation and study of new design artifacts remain sparse in the HCI community.

Our research aims to contribute specifically to this intersection through investigating three key objectives. First, we aim to inquire into how making people's digital photo archives more present, dynamic, and interactive with different temporal pacing of clock-time might open new possibilities for situated, reflective memory-oriented photo viewing; we attend to how photos can momentarily act as cues to trigger moments of reflection on the past in relation to the lived present. Second, we want to better understand how temporal metadata might operate as a resource for generating alternative perspectives on and a renewed awareness of people's personal digital photo archives. Third, we investigate life history as a quality of temporality raised by *slow technology* [34, 63] and explore how this framing might offer a rich way to support ongoing and indeterminate experiences with digital photo archives that change over time.

To pursue these research goals, we designed, implemented, and conducted an eight-week field study of *PhotoClock*—a mobile application that reconnects people with their memories through presenting photos previously taken at the 'clock time' of the present moment (See Figure 1). Leveraging temporal metadata, PhotoClock enables its users to revisit their personal digital photos through three pacing modes (Hour, Minute and Second). Each mode presents photos in a specific length and movement of time which is tied to the current clock time. These modes let people observe how their photo archive is structured across different temporal vantage points through a 24-hour lens, and supports them in experiencing the perpetual, ongoing flow of time. Offering a minimum degree of control, the PhotoClock design opens possibilities for people to encounter a wide range of unknown, forgotten, or discrete memories captured in different points in time through the presence of their digital photos (See Figure 2). While its interaction design is relatively minimal and subtle, it takes time to understand and offers potential to catalyze various open-ended experiences in relation to curiosity, contemplation, and perception of memories interconnected through time.

We created a highly robust research product [66] version of the PhotoClock application and deployed it with 12 participants in North America for eight weeks, using it to open a dialogue with participants about the reflective potentialities of memory-oriented photo viewing through the lens of clock-time; and, to explore their experiences of living with an application that continually changed over time through the lens of slow technology. Findings revealed that PhotoClock became integrated into participants' everyday practices and catalyzed a range of reflective experiences on their respective photo histories and life stories. They also showed that perceptions of PhotoClock changed over time and opened alternative ways of considering time and the potential longevity of personal photo archives.

This paper makes two contributions. First, it provides insights on how a design intervention can support memory-oriented photo viewing by making one's digital photo archive accessible through different pacing of clock-time. Second, it offers a case that helps expand strategies for designing slow technologies that can be accepted into people's lives and dynamically change with them through time.

2 LITERATURE REVIEW

The related work falls into three sections: digital photo viewing experience, remembering through personal data, and expression of time.

2.1 Designing Interactions with Digital Photos

Photographs are one of the most pervasive and extensive forms of digital possession that people have. Yet, challenges have emerged as people transitioned from using solely physical photos to incorporating digital photos in their everyday lives. Without a material presence, digital photos are easier to preserve, share, and accumulate over time [68], but this quality also makes it difficult for people to grasp how vast and fragmented their photo archives are [89]. Various studies have investigated people's photographic practices in the digital world and discovered that people seldom have the motivation and patience to work on photo management (e.g., [9, 49]). This phenomenon may result from the difficulty in deciding which photos they want to preserve, revisit, or forget [57]. Researchers have shown that tensions associated with such decisions can become further amplified when it comes to romantic breakups [39, 40, 78] and the death of loved ones [64, 79].

Recently, there has been a growing amount of HCI research focusing on designing more diverse approaches for supporting people in interacting with their digital photos for experiences that include personal reflection [60, 85], identity construction [18, 19, 36], and

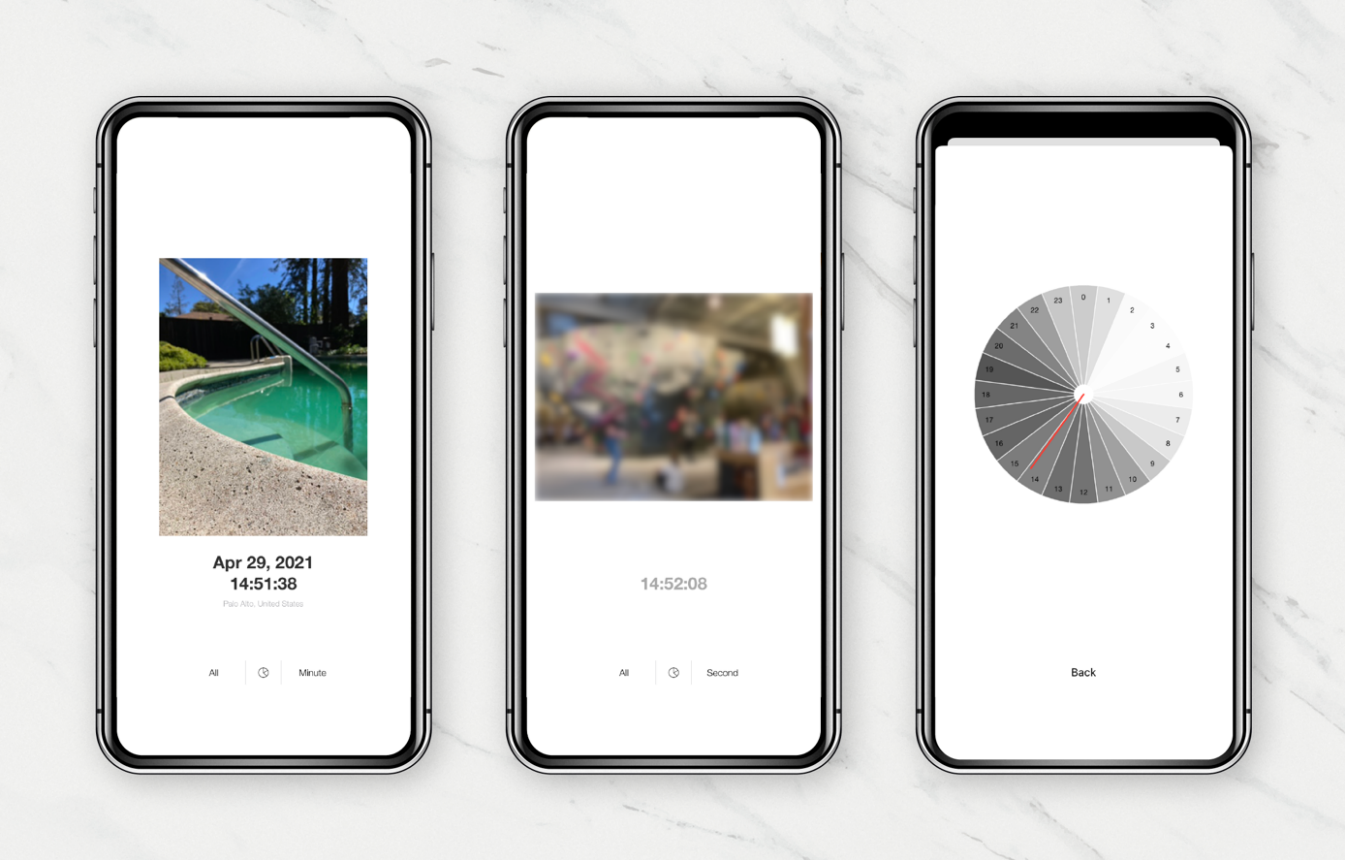

Figure 2: The user interface of PhotoClock. Left: The user sees a photo clearly with all the metadata presented in the page. Middle: In a special case, the user sees a blurry photo and it gets clearer as time goes by. Right: The user enters the Sunburst page and see how many photos were taken in this device throughout the 24 hours. The darker the color is, the more photos were taken within that particular hour.

self-growth [17, 54]. Yet, the exponential growth of personal digital photo archives continues to create difficulties for people to access and engage with the photos, thus complicating their ability to operate as valuable resources [9, 89]. According to Bergman et al. [4], even with the advancement of mobile technology, people still have major issues in searching for and re-experiencing key meaningful digital photos. Conventional interactive forms and techniques, such as albums, scrolling galleries [3], slideshows [1, 3], keyword searching, and face recognition do help, but more diverse and alternative design approaches are critically needed [4]. Beyond an individual focus, digital photos also operate as important resources for collective remembering and intimate communication among loved ones [2, 37, 81] and family members [20, 21, 52, 86, 87, 89]. Yet, few works have investigated how one's digital photos could be presented, visualized, and revisited as a whole to create a sense of life journey or personal history for oneself, let alone sharing them or passing them down to others.

Overall, these collective works showcase that, while limited, there is an increasing interest in investigating new ways to engage people in experiencing and interacting with their personal digital photo archives. They also highlight the critical tensions that come with massive personal digital photo archives and the need for a multiplicity of approaches that can enable people to get a grasp of their archive and experience it from different vantage points. Our research aims to build on and extend these works by creating, deploying, and studying a novel application that supports rich, open-ended interactions with personal photo archives through time.

2.2 Surfacing Memories through Personal Data and Informatics

The HCI and design communities have had an ongoing interest in how personal data can be leveraged to support personal reflection on everyday experiences [15, 24, 32, 68, 75] and life histories [14, 23, 43] in ways that are open to ongoing interpretation [76]. In parallel, there exists an increasing amount of work advocating for creating technologies that expand beyond "*an exclusive interest in performance, efficiency, and rational* [self] *analysis*" [25, p.48]. To this end, HCI and design researchers have articulated new opportunities for using metadata "as a resource for people to manipulate and personalize their virtual possessions" [68, p.991]. Through the

Curatorial Agents project, Gulotta et al. proposed that temporal metadata can be leveraged "as an important factor in the meaning-making process [and] could be a contextual variable that helps situate digital information [for] evocative, meaningful, or relevant experiences." [32, p.3460]. Collectively, this research helped open opportunities for seeing metadata in a new way for design – not simply as a by-product of the creation and use of personal data, but as a potential design material for supporting new ways of viewing experiences from one's past from different perspectives.

Following this work, nascent research has utilized temporal metadata as a design resource to explore how it might generate new experiences of reminiscence and reflection [25, 68]. For example, music players such as Olly [65], Olo Radio [67], and Musée [47] use user's music listening history to resurface songs people once felt strongly connected to at a certain point in their past. Chronoscope [12] provides alternative ways of sorting digital photos such that people could observe their life patterns through different temporal lens. By combining photo and audio media in one tangible artifact, Slide2Remember [48] is a wall photo frame that plays songs that people heard at the period the photo was taken. These earlier works encourage leveraging temporal metadata as a design material to support new kinds of open-ended experiences with personal data. Yet, few works have applied this design resource to address and reconstruct different memories through and across time in the context of digital photos.

Our work seeks to directly build on this prior research through contributing a novel design and field study that investigate how temporal metadata can be leveraged as a design resource to enable interactions with digital photos that are dynamic, generative, and ongoing. We discuss opportunities for memory-oriented photo archive interactions through a temporal lens, and reflect on how this alternative design approach can open a space for interpretive explorations of one's life history in relation to different moments and periods of the day.

2.3 Attending to the Presence, Expression, and Ongoingness of Time

The scale and depth of different points in one's life history that are bound up in a personal digital photo archive are what motivated us to explore how digital photos could be re-experienced through a temporal lens. In their foundational research on slow technology, Hallnäs and Redström argue that design practice must embrace a longer temporal trajectory to create "technology that surrounds us and is part of our activities over longer periods of time" [34, p.203] and that emphasize the "presence – not absence – of time." [34, p.204] Since this foundational work, there has been a growing interest in exploring slowness and temporality as frames for the design of new technologies. Galani and Clarke [28] applied a slow technology framework to catalyze imaginative experiences through an augmented reality museum installation. Grosse-Hering et al.'s Slow Juicer [31] and Pschetz and Banks' Long Living Chair [71] each mobilized slowness to give rise to meaningful reflections on embodied practices with each artifact respectively, prompting reflection on one's relation to them over their lifetime. A nascent set of works have explored how slowness could support meaningful experiences with digital data. Examples including the Reflexive Printer [85], Photobox [62], Olly [65], Postulator [35] and Family Stories [41] provide evidence that slowness can be a resource for supporting rich experiences, such as anticipation and reflection. Yet, these systems enforce a 'slow' pace by restricting nearly all control people have over the system itself.

Recent research has advocated for the need to create new approaches for advancing the aspirations of slow technology through design in ways that offer people some control over the system, while not compromising the richness of this approach [51, 63, 70, 72, 84]. In this context, researchers have turned to embrace alternative conceptualizations of time. Several works, such as rhythms of pause [27], crescendo expression [84], and culturally relative notions of time [83], have articulated the importance of temporal structures in the design of interactive experiences. Pschetz and colleagues [7, 72, 74] argue that designing for slowness in the literal sense may result in an oversimplification of the dichotomy between fast and slow by treating 'time' as solely a matter of pacing. Rapp [73] proposed new opportunities for temporal technologies to enable more "malleable" representations of time with added control over the velocity of the interaction pacing. Collectively, these works highlight the need for research that explores temporal diversification through design and people's lived experiences of it.

Our work aims to contribute to these strands of research on slowness and temporality. Through our field study of PhotoClock, we seek to explore how 'time of day' embedded in the timestamp of every digital photo and the perpetual ongoingness of time could come together to create a subtle expression to meaningfully reconnect with one's past.

3 METHODOLOGY

Our design research process was influenced by the concept of *research products* [11, 59, 66]—design artifacts that are created to drive a research inquiry and that have a high quality of finish. Research products are created to operate independently over time to support field studies of their use in people's everyday environments. Following prior work (e.g., [67]), this approach is particularly well suited for supporting empirical studies of slow or temporal technologies because these systems often take time to understand and require experiences and interactions to accumulate with them over time. We created a highly robust, resolved, and deployable version of PhotoClock as an iOS application. Next, we summarize key parts of our design process to highlight important qualities of our final version of PhotoClock.

3.1 PhotoClock Design Process and Implementation

Our design of PhotoClock is highly influenced by conceptual propositions that we arrived at through close readings of theoretical articles on slow technology [33, 55, 63]. Our research framing is shaped by a synthesized set of slow technology's propositions of creating technologies that: *preserves time for reflection*; *manifests change through time*; *modulates pacing of interaction;* and *generates interconnections across time in everyday life*. In line with these foundational conceptual aspirations, we are inspired by two design qualities – *ongoingness* and *pre-interaction* – proposed in recent research that aims to extend the theory of slow technology for design

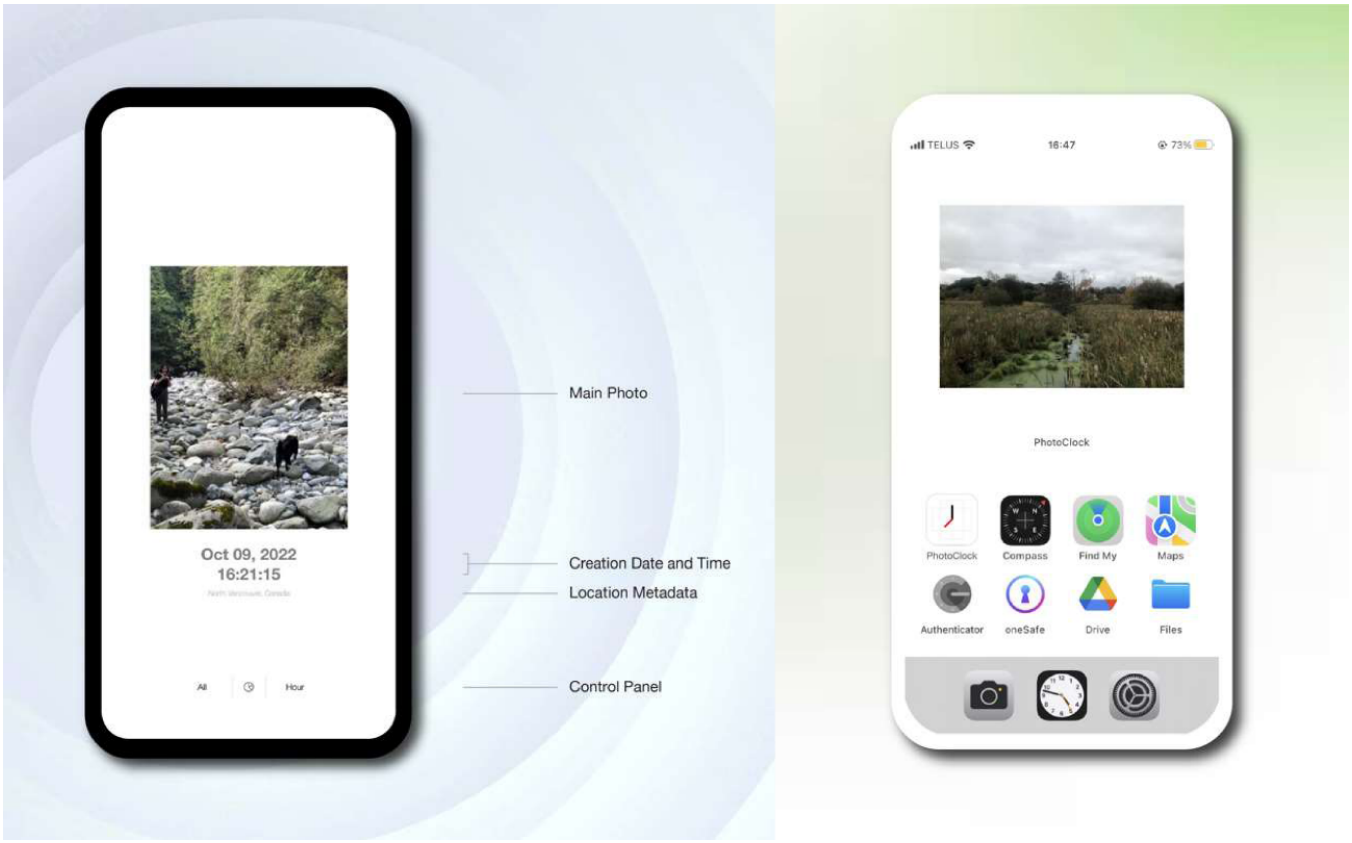

Figure 3: Left: Using the current clock time, the PhotoClock app finds a photo taken around the same time of day in the past and presents it alongside with the temporal and location metadata to its user. The Control Panel displays the current selected filter and mode; Right: The PhotoClock widget presents a new photo every hour exactly like what users would see in the Hour mode. Tapping either the PhotoClock app or its widget on one's home screen will lead its user to the app.

[63]. The *ongoingness* quality focuses on the perpetual movement of time, which "evoke[s] a recognition by the user that the artifact is continually changing alongside them, albeit at its own pace" [63, p.174]. *Pre-interaction* emphasizes anticipation and contemplation through "refocus[ing] attention to the expanded set of experiences that could be considered and designed for prior to interaction with the artifact itself" [63, p.174]. Prior research has speculated that these design qualities can come together synergistically to "project a co-evolving quality that is unique and distinct to the user, that times time to interpret, and that can scale to evoke cumulative change over time" [63, p.174].

Nascent design research exploring slow messaging systems, such as *Future Me* [58, 69], *Slowly* [90], and *CrescendoMessage* [84], have shown that asynchronous, enforced delay of interaction with personal digital records from one's past may lead to arbitrary perceived connections among the present moment and to a past event as the user compares two different times. In these cases, the end user often has very reduced control over the system during elongated moments of pause until the next digital record is revealed. To support an ongoing and subtle feeling of revisiting one's digital photos, we became interested in the notion of *nowness* that is shaped by a sense of present time in which "*time flows unbrokenly forward at a natural speed*" [53, p.1641]. This motivated us to take an approach that creates temporal interconnections among the relatively precise present time of day and the past clock times of when one's digital photos were taken. Our goal is to provide an ongoing sense of nowness in the interaction flow in which people not only reconnect to their past across different days in life but anticipate what photo memories might 'come and go' as time flows. By designing PhotoClock, we want to understand how these qualities can be integrated to inquire how clock time might support a type of temporal flow that can dynamically connect people's present moments to their past memories.

3.1.1 Integrating Ongoingness and Pre-Interaction with 24-Hour Cycle. PhotoClock allows people to explore and interact with their digital photo archives through three basic features: *pacing modes*, *archive visualization*, and *selection filters*. When the user launches the app for the first time, a loading screen appears to access photos from the local iOS library on the user's smartphone and build a new database based on which hour, minute and second each photo was taken in the past. Once this process is completed, the main page

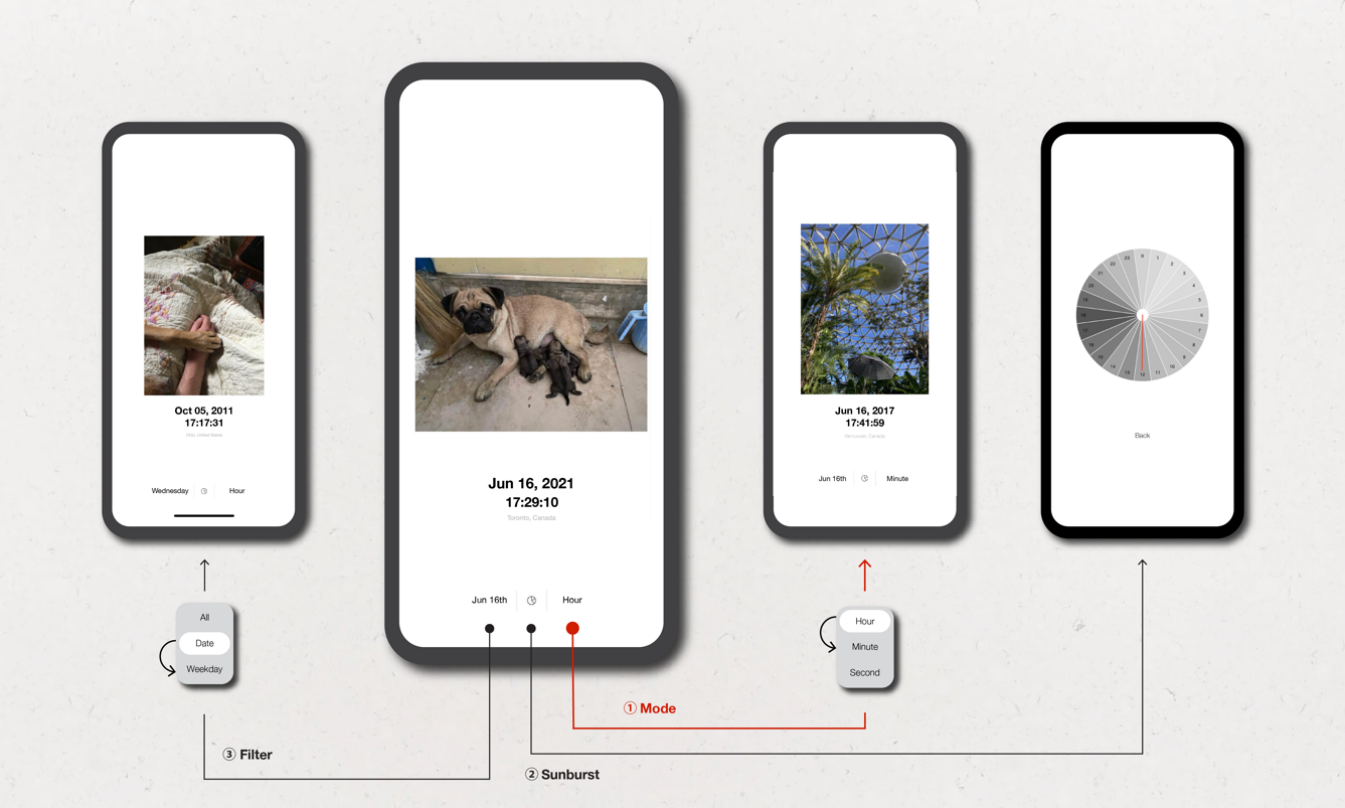

Figure 4: There are three buttons in the Control Panel for user to interact with this app. ① The main button on the right toggles between the three pacing modes (Hour, Minute, and Second). ② The middle one with a pie chart icon on it stands as an entry to the Sunburst page. ③ The left one allows its user to toggle between the three selection filters (All, Date, and Weekday).

will fade in and start displaying photos according to the clock time (See Figure 3).

Recent research has suggested that building in support for users to modulate the pacing can help mitigate tensions around lack of control without compromising the reflective, interpretive, and ongoing qualities of slow technologies [67]. Extending this work, we decided to create three pacing modes: **Hour**, **Minute**, and **Second**. Each mode selects photos from a different unit of time and provides a different rhythm in transitioning photos. Hour mode displays one photo per hour drawn randomly from that stack. For example, when it turns 5pm, PhotoClock will randomly select one photo from all photos taken between 5:00-5:59pm. This photo will remain present until it turns 6pm. At that time, PhotoClock will randomly select one photo from all photos that had been taken between 6:00-6:59pm, and so on. The process is ongoing, slowly changing with each hour indefinitely. Under the hood, the PhotoClock system knows the temporal and locational metadata about the photo that is being displayed. But each timeframe mode is not relational to each other – if a user were to change from Hour to Minute, a new random photo selection will occur and be taken from the stack in the newly selected mode (See Figure 4). If the photo being displayed during the Hour setting at 5pm was taken at 5:29:10pm but in real time the clock time is 5:41pm, and the user changes the mode to Minute, a new photo will be selected from the 5:41pm stack in the Minute mode (i.e., from all photos the user had taken at 5:41pm across time). Then, when it turns 5:42pm, PhotoClock will select a new Photo from the 5:42pm stack, and so on. If the user were to shift the mode back to Hour then a new photo will be randomly selected from the entire 5pm stack. If the Second mode is selected, then the app will pick a new photo every second (e.g., at 5:41:45pm, 5:41:46pm, 5:41:47pm). Again, like in all stacks, in the default setting, PhotoClock will aim to randomly select a photo from each stack (down to the second in this case). Thus, it is possible that a photo will be displayed each second, continually moving forward in time.

We deliberately designed PhotoClock to be minimal so that people would focus on the photo itself. In addition to the primary screen which transitions the photos indefinitely through time, we created a secondary **Sunburst page** that illustrates a 'clock-like' representation of time. This form draws inspiration in part from the *Slow Watch* 24 hour timepiece [13]; in our case, it shows the relative density of photographs on a 24-hour clock. Through this clock-like visualization, people could observe the number of photos they have taken within each hour of day and reflect on the reasons behind this visualized information.

Inspired by the data *wayfaring* concept where Rooksby et al. [75] argue that people do not follow a set path to their imagined

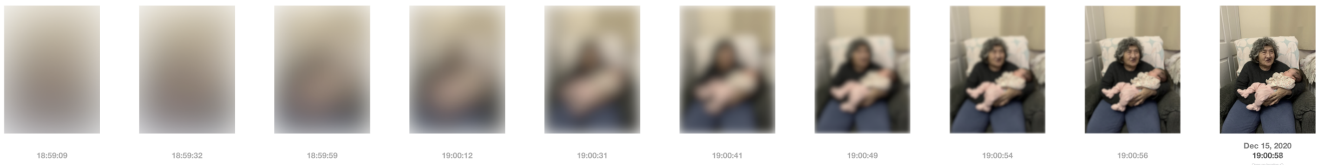

Figure 5: An example of how the PhotoClock system deals with empty moments. It applies Gaussian Blur to the picture every second at a level based on how far the picture should appear in time.

future but wish to navigate their lived experience through using a variety of information (such as personal data), we decided to allow PhotoClock's users to observe cyclical life patterns by **a** filter changing button. This button toggles among *All Photos*, *Date*, and *Weekday*. *All Photos* means that the system does not apply any filter, so all of the user's photos would be considered by the system. The *Date* filter only show photos taken around this time of day on a specific date, such as all photos taken on July 7th throughout the years. The *Weekday* filter filters photos from a specific day of week such as Sundays.

Collectively, PhotoClock's three features enable people to view their digital photos in various timeframes. However, there is one special occasion that would lead to a 'blank' state in the system. That is, it is possible that a photo may not be available in the user's archive. Probabilistically, it is less likely for this to happen in Hour mode (but it still could if, for example, a user has never taken a photo between 7:00pm-7:59pm). When in Minute mode, it becomes more likely that a user may have a 'blackspot' or zero photos in some stacks (e.g., at 7:00pm, 7:01pm, etc..). In Second mode, the probability increases dramatically that a user may have blackspots in many stacks in a serial order (e.g., 7:00:12pm, 7:15:13pm, 7:15:14pm, etc.). We call this kind of blackspot **'empty moments'** which we saw as a design opportunity for supporting *pre-interaction*. When this occasion happens, PhotoClock applies a certain level of opacity where PhotoClock will 'jump ahead' and find the next closest photo that will be available in the respective selected pacing mode, and then slowly fade that in based on the gradation of time. For example, assume that it's 6:59:09pm and there is a series of blackspot stacks up until 7:00:58pm where the next photo appears. PhotoClock will then 'lock onto' that photo at 7:00:58pm and then as each second passes, progressively getting closer to 7:00:58pm, the photo will slightly fade in, become easier to see until 7:00:58pm when it is fully revealed. This design decision is inspired by the CrescendoMessage project [84] which effectively utilizes blurriness to support people's anticipation and curious exploration of one's digital photos. This is also an important part of how the logic of PhotoClock works and how it compensates for blackspots in stacks (See an example in Figure 5).

What if the user changes the pacing mode when it is currently showing a blurry photo? Under the condition that the mode is changed from higher to lower level (e.g., from Hour to Minute, or from Minute to Second), the system would select a new photo from the smaller stack. When the mode is changed from lower to higher level (e.g., from Second to Hour), there are two conditions. If the photo was taken within that hour (the larger stack), the system will show it 100% clearly immediately. If the photo was not taken within that hour, the system will pick a new photo from the larger stack. We designed the PhotoClock this way in order to support people to perceive and interpret the empty moments in their photographic history, as well as to create a sensitivity to different scales of time.

Despite the three different features, PhotoClock's interaction design remains relatively minimal. It points the user to a moment back in time related to the presently lived moment. As more photos are accumulated in the user's everyday life, PhotoClock continually forms connections to various points in time and shape a photo archive bound to the 24-hour system. Inspired by the concept to *create technology that requires time to understand* and becomes part of people's practices over time [55, 63], the aim of these design decisions is to use minimal guidance for PhotoClock to catalyze a range of experiences for people to sense the growing scale of their digital photo archives and the potential relations hidden between different photo memories.

3.1.2 Implementing and Distributing PhotoClock to Inquire into People's Everyday Experiences Over Time. We decided to develop the research product version of PhotoClock in the form of an iOS app which can be installed on iPhones, iPads, and Apple's M1-chip computers. Reasons are that it is one of the largest mobile operating systems [91], and that it is much easier and faster to manage image metadata and build a 24-hour structured database with its API support from Apple PhotoKit. The latter reason is especially important because image processing in real time requires a substantial amount of computation that would inevitably affect people's experiences interacting with their large and still growing digital photo archives. Additionally, we want to enable people to use it anytime and anywhere at their preference. Clearly, these decisions come with tradeoffs. For example, in the future PhotoClock (and applications like it) could be made accessible to a wider population that uses other operating systems (like Android). Yet, as an initial step, we decided to use iOS to ensure a highly robust, finished, and deployable version of PhotoClock could be created.

When the user enters the PhotoClock app for the first time, the system accesses the local library in Apple Photos and loads every digital photo's identifier into an in-app sophisticatedly structured database. Each photo identifier stored in the database enables the system to find the local photo file directly for faster access to its image content, as well as its metadata such as when and where the photo was taken. In this database, we created a hierarchy of three levels — Hour, Minute, and Second. The stack structure is shown in Figure 6.

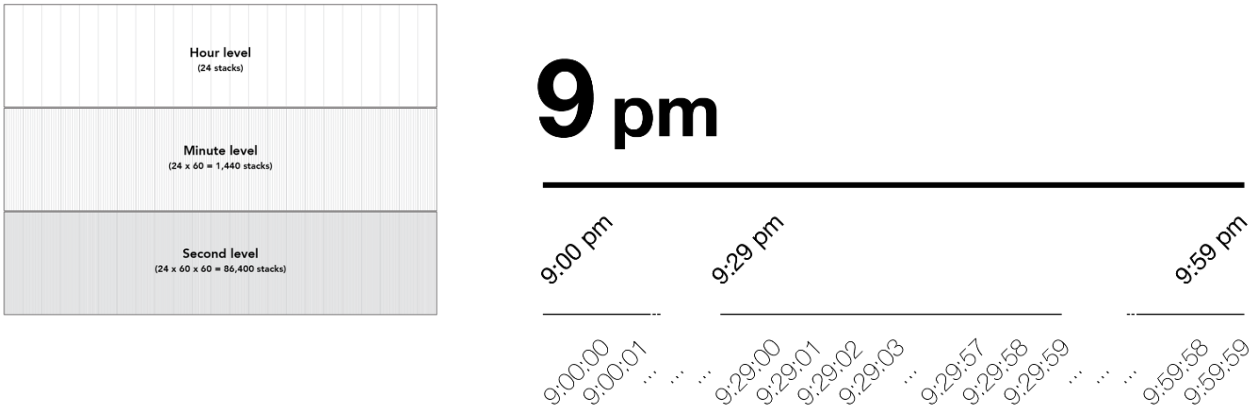

Figure 6: Stacks hierarchy of PhotoClock. Photos taken within a specific time period will be put into the same stack. The system selects a stack based on the current clock time, and randomly picks one photo from the designated stack to show its user. Every photo identifier is stored in a specific second stack, depending on which hour, minute, and second the photo was taken (e.g., 9:29:17pm), irrespective of date and year. While every second stack is a subset of a specific minute stack (e.g., 9:29pm), every minute stack belongs to a larger hour stack (e.g., 9pm).

With this time-structured database, the PhotoClock system can easily select photo from the current time stack in real time and smoothly switch between the three pacing modes. Yet, people's privacy is fully respected in this PhotoClock app. It only requires local access to all photos in their device. No usage data or any photo content is collected. If the user decides to delete the app, all the database and stacks will be erased entirely on their device.

Collectively, our implementation allows PhotoClock to offer an ongoing experience to revisit a series of personal moments in one's past. More importantly, we consider this implementation phase an important step to ensure that the PhotoClock app is highly robust and resolved before our distribution to real-world participants in the final deployment study. Next, we describe the details of participant recruitment, data collection and analysis of the study.

3.2 Field Deployment Study: Participants, Data Collection and Analysis

We recruited 12 participants from North America through word of mouth and snowball sampling methods (specific location withheld for blind review). Similar to the aim of the original technology probes paper [46], we focused on a small selection of participants to collect rich and descriptive qualitative data in order to gain deep understanding of our targeted research topics. We use pseudonyms to describe participants. We decided to select these participants because, taken together, their respective digital photo archives and photographic practices had shown considerable diversity in terms of size and image content (see Table 1).

Each participant had their PhotoClock app installed at the start of the study. All interviews for the study were conducted over a secure video conferencing application. In the initial interviews, we learned participants' photographic practices and, more generally, their daily lives and practices. We offered a demo of PhotoClock and provided a document briefly explaining how it works. We explicitly noted that they could develop their own interpretations of PhotoClock based on their interest in using (or not using) it. All were aware they could drop out of the study at any time.

After the initial setup, we conducted bi-weekly check-ins with participants over the 8 weeks. We aimed to probe the degree to which PhotoClock prompted reflective, temporal reminiscence, or other memory-oriented experiences over time (see Figure 7). We were also interested in whether unexpected connections across photos were revealed or if participants encountered photos that they did not remember taking to understand how these experiences were reconciled. The final in-depth interviews lasted approximately one hour. Two researchers attended and took notes in each interview. Notes were reviewed immediately after each interview, and tentative insights were noted in reflective field memos [30]. All interviews were audio recorded and saved confidentially to a secure storage unit. After getting a set of verbal transcripts from an automatic transcribing service named Otter.ai, we manually corrected the misinterpretations in the output transcripts. The final transcripts were then coded by two members of the research team, using a hybrid approach involving first deductive and then inductive coding. After each interview, we conducted a preliminary analysis, including a search for themes of stabilizing and shifting patterns across our data that were later drawn out as underlying themes [56]. We coded raw documents with these themes and created affinity diagrams to model connections and differences among participants. Ultimately, this process yielded 5 main themes, such as *general usage*, *ephemerality and dynamics*, *reflection on the passage of time*, *life patterns and memories*, and *longevity and cumulative experience*.

Table 1: Participant Profiles

Participant	Lori	Ashley	James	Pamela	Timothy	Keith	Melissa	Rebecca	Walter	Natalie	Sasha	Denise
Age Gender Profession	25-34 woman Theatre Studies	18-24 woman Virtual Reality	25-34 man Data Visualization	25-34 woman Biotech	25-34 man Virtual Reality	18-24 man Virtual Reality	25-34 woman Machine Learning	35-44 woman Photography, Language	25-34 man Interactive Media Arts	18-24 woman Digital Product Design	35-44 woman UX Design, Administrator	25-34 woman Film Production
Cultural Background	Taiwanese	Persian	Latino	Taiwanese	Chinese	Indian	Taiwanese	American	Indian	Arabic	Pakistanis	Taiwanese
General Types of Photos	Travel, daily life, cat, nature	Friends, family	Pets, travel, partner, food	Important others, travel, food, daily life, her cat	Memories about life	Sunsets, portraits, night skies and people	People, pets, scenery	Friends, family, places, pets, mundane moments	Friends, places, artefacts	Friends, fashion, food, scenery	Food, family, special events	People
Total Number of Photos	19,266	25,762	5,000	1,678	11,008	41,766	23,415	12,579	54,477	8,479	1,000	30,009

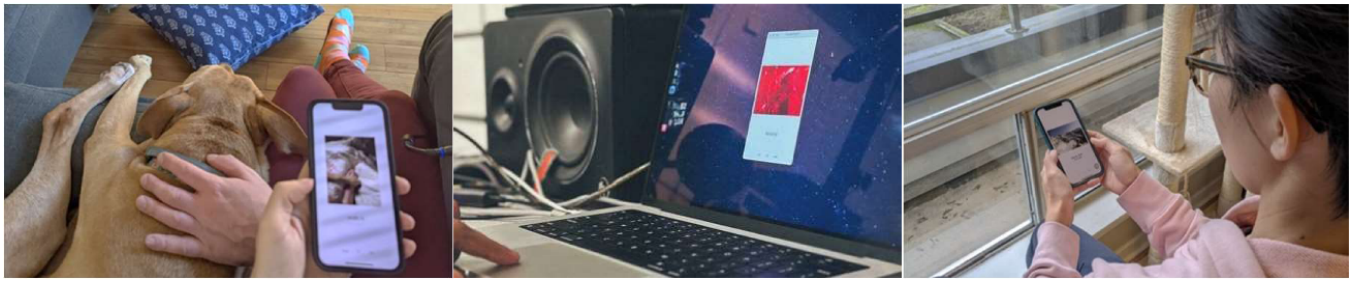

Figure 7: Left: While PhotoClock was showing Rebecca a photo of her taking care of a friend's dog at a Thanksgiving gathering a few years ago – here she was sitting with the same dog at the moment she viewed the photo. Middle: In parallel with using the app on iPhone, Keith would run the PhotoClock app on his M1 Macbook Pro. Right: Melissa used the PhotoClock during her work breaks while remote working at home.

4 FINDINGS

In this section, we describe examples taken from the interviews that best illustrate themes in our findings with a focus on how PhotoClock mediated photo viewing experiences in relation to memories, reminiscence, and temporality. To better contextualize the thematic findings, we offer a brief overview of participants' existing photographic practices. Across our initial interviews, it was common for participants to express uneasiness over the whereabouts and provenance of significant digital photos, and desired for new ways to generate engage with their respective archive's contents, as captured well by **Rebecca**:

> "Even professional photographers have lost significant amount of their work through hard drives failing or SD cards being corrupted. There's plenty of reasons to not expect digital photos to last forever. Also, it's really easy to lose track of them in the digital form. . . .Even with my own family photos, [they are] all in [physical] photo albums. How do you make sure you are able to share your digital photos with your family in a way that they can access and understand what's going on? We might lose a lot because they're digital." (**Rebecca**)

The complications and desires communicated by our participants are generated from a lack of control over and awareness of their personal digital photo archives matches findings from prior HCI research [4, 9, 49, 68, 89]. Collectively, it is obvious that currently available tools may not be adequate to address the scale and fragmentation of participants' photo archives and triggered ambivalence over how they will engage with them as they continue to grow. Even though social media such as Facebook and Instagram have provided the 'Memories' feature that allow people to reflect on their previous photo posts, them reported that the feature is quite restricted to their public image and that it only shows posts on the same date of the year from before. However, all participants desired to continue creating, accumulating, and sharing digital photos indefinitely into the future.

Overall, during the field study period, 9 participants reported that they have used PhotoClock multiple times every day while other 3 participants used it for two or three times a week. Eight participants decided to add the PhotoClock widget to their home screen at the start of the study. Next, we

present findings that detail the range of experiences participants had with PhotoClock throughout our field study.

4.1 Viewing Digital Photos Based on the Present Clock Time

Prior slow technologies have encountered tensions that complicate their acceptance and adoption as frustration emerged for participants due to a lack of control over the technologies they lived with (e.g., [29, 35, 58, 85]). The PhotoClock design aims to extend a degree of control to users through the pacing modes, while being unable to fully 'stop' the flow of time. As our study progressed, we observed that participants shifted their focus from discovering memories as they were, to reflecting on multiple life events altogether. Yet, its three pacing modes could also take time to make sense of, at times causing frictions around their intelligibility and intention. In the following subsections, we unfold participants' perception of PhotoClock's three pacing modes.

4.1.1 Perceiving the Transition of Memories Dynamically through Second Mode. Participants widely reported *Second* as the pacing mode that they started with when beginning to use PhotoClock. This mode–which tended to display a set of photos taken in the same event or historical time period–appeared to help participants contextualize photos and prompt recollection of memories, as compared to viewing only a single photo. For example, **James** reflects on encountering snippets of memories in sequence:

> "I usually take multiple photos in succession, so this mode groups snippets of moments in time, like short memories. . . .Individual pictures didn't always take me down to that specific moment, but seeing the series of 4 or 5 pictures definitely brought back the memories, such as being cold but happy during the convocation, trying different beers in Nova Scotia, and enjoying the sunny days walking around the pyramids in Teotihuacán." (**James**)

Similarly, **Keith** found *Second* mode helpful in picturing the progression of his past events. He was able to trace his various attempts at taking a satisfactory photo and recognized value in the 'gaps' as photos transitioned from one to another:

> "I take a lot of [photos] which are blurry or in different exposures, different camera lenses, so I had moments where I could see my failed attempts and then finally get to the one which I chose. . . .I could see the process behind the actual events. . . .There's often awkward pauses like something would happen, like traffic would pass, or like we would stop. There's a few seconds where it would be blurred until the next photo, and I started remembering what happens in that sequence. Pretty interesting context–to see the gap between photos." (**Keith**)

However, when Second mode displayed a sequence of photos from distinct events, some participants found it difficult to contextualize the photos in a very limited time span. The momentary, ephemeral presence of such photos could create a sense of anxiety and, in some cases, participants reported desires for a pause button that would give them more time to reflect on each photo. This situation happened more often for participants who had much smaller archive like **Sasha**:

> "Second [mode] gives me stress. As soon as I saw a photo, something else showed up. I was like, what did I miss? I knew I forgot something, but I just didn't know what [it is]. It moves so fast that I kind of lose whatever emotion I have." (**Sasha**)

Walter communicated experiences of both intrigue and bittersweetness as he witnessed multiple memories dovetail into each other and a bigger picture of his earlier school life emerged:

> "[It's] interesting to experience all the overlapping of different events. . . .I've been wanting a pausing button for the Second mode, but I feel complicated about it because I do appreciate the app giving me a sense of 'real time flow'. That's the way time works. We have no control over it. But, how can we deal with it? Some memories I can never experience again, and maybe it's great that I learn how to let the memories come, and then take a breath to let them go again." (**Walter**)

Collectively, these examples illustrate how participants leveraged PhotoClock to examine traces of their past self and to move across different times of the day in the Second mode. This, in turn, could lead to either an overwhelming feeling of not being able to restore memories right away before time moves on to present another photo, or an overall awareness of one's entire life history, with and without photos. They also hint at tensions they may emerge with smaller archives that may fade or change over time as the archive grows larger. Next, we describe what photo viewing experiences could be primed at a slower interaction pace with the Minute mode.

4.1.2 Sensing the Visual Expression of Memories Slowly and Emotionally in Minute Mode. When participants reflected on their experience with Minute mode, they often pointed out that it was easier to focus on the visual expression of the photos PhotoClock presented. For example, **Denise** recontextualized a faraway yet pleasant memory triggered through a static representation of scenery:

> "When you use Minute mode, you can think about that photo and remind yourself what happened during that time instead of just a bunch of photos snapping in front of you all the time [like in Second mode]. ...It was one sunset photo in Seattle, at the hill in the Gastown. I don't know why, but it was kept in my brain for a while. It was just calm and really happy. I was visiting my cousin. He introduced his friends to me and then we had a good time just walking around the parks and seeing the old facilities left there for 100 years." (**Denise**)

Moreover, **Natalie** remarked on how the Minute mode was suitable for her to effectively relive an unexpected moment a few years back when she was in a different city:

> "When I used Minute mode, it's less about the time itself and more about the location and the content. Because when you browse photos, you specifically look for something. But with PhotoClock, the photos just show up in a way that caught me by surprise. You have to accept what you're seeing in front of you, instead of actively looking for the memory. . . .There is a photo of the museum in Boston. When it showed up on PhotoClock, I felt like, wow, it definitely brought back memories of the time, who I was with, and even the feeling of being there. Moments that I didn't think were important to me at the time could actually make me feel really appreciative towards them now." (**Natalie**)

For **Ashley,** the Minute mode offered a valued prompt for reminiscence compared to the pacing of other modes:

> "Minute mode is my favorite. ...It is a good balance for me to go through memories between too fast [Second] and too slow [Hour]. . . .Most of the photos I saw were taken in my home country, Iran. . . .70% [of them] were from the past memories that I have forgotten or have not visited for a long time. It made me both sad and happy. How much can things change? How much can people change? And what you don't realize is how fast things go by. It was a very emotional roller coaster for me to hold up." (**Ashley**)

However, some participants felt anxious while waiting for the next photo to appear. They reported a clash between PhotoClock's pace and their desired pace. For **Melissa**, frustrations could emerge when she encountered a 'gap' in and was unaware of when a photo would become fully resolved and unblurred:

> "Sometimes, I saw a blurry picture, and I would wait for [a clear picture]. But I wish it would be able to appear faster. I keep waiting, keep waiting, and then finally, it shows up! But I was interested in the next one [already]. I had to wait for the next minute [to come]. . . .I think the pace could be adjusted, either to be faster or slower, depending on the situation." **(Melissa)**

Overall, these examples illustrate how participants leveraged the Minute mode's pacing to engage with moments of reflection on traces of their past self. Next, we dig deeper to see how Hour mode offered yet a different perspective on and mediation of people's experiences with their photo archive.

4.1.3 Manifesting Time of the Day in a More Prominent Way with Hour Mode. With Hour mode, we discovered that participants were more likely to ascribe meaning to a specific periods and daily patterns across different life stages. For **Natalie**, viewing various photos from around the same hour of the day helped her establish mental associations among her past routines:

> "Eight pm in Boston, 8 pm in Vancouver, or sunset in San Francisco. . . Most of these beautiful things took place in the evening because during the daytime, I was always in college or working, so, it was interesting to think about my routine at the time, the hour that was associated with my life at the time. . . .Hour mode makes me think about those times in a more prominent way. It signifies more things for me versus the other two modes just because they don't really solidify things for me in a way. I would think about what I was doing at a particular hour, but not for the other two modes." **(Natalie)**

Participants also reported that the widget was a befitting medium in the case of Hour mode. In the following quote, **Keith** was able to appreciate the slow pace of changes happening in the background:

> "This was the most pleasant mode. Most passive and least anxious. I didn't feel the need to click on anything. I just viewed the image and nothing else. I wasn't anticipating a refresh. That's why it works the best in this widget format." (**Keith**)

In parallel, participants often used the Hour mode in combination with the Sunburst feature for self-reflection and discovering patterns throughout the day. This theme is best captured through **Rebecca**'s reflection:

> "Most of my photos were taken when I was travelling, so it makes sense that there would be a bulk of images during the middle of the day. . . .This one [photo] is geese in the river. It was a morning walk from when I was in Prague. It wasn't any crazy, important image, but it made me realize certain patterns or rhythms to my day. I go on lots of morning walks in Vancouver. I do the same thing even when I'm home. I have a bunch of pictures of herons because my partner and I have a heron challenge where we'll try to get points for who sees the most heron. . . .I also wonder what I did early in the morning. What would I see if I opened PhotoClock at four in the morning?" **(Rebecca)**

After using Hour mode to examine the life patterns depicted in the Sunburst page, some participants desired more controls over seeing more contexts or interacting more with the Sunburst visualization. **Sasha**, for instance, mentioned that it was the empty moments she perceived from the gradational colors in the Sunburst page that gave prominence to her own life patterns and made her curious:

> "I liked the empty moments. I liked the [darker and lighter colors in] Sunburst because it showed me some patterns. . . .What would be nice is that it could give some more context rather than me actually looking for the photograph [back to the main page]. ...I would like to have some people's tags on the photograph. Some metadata that actually speaks volume like what is included in this particular Sunburst. Then if I'm interested, I would click on this slice of hour, and it would show me photographs in the hour." (**Sasha**)

Our findings show Hour mode provoked numerous instances of recollection and reminiscence on past memories among participants. Further contemplation was prompted through the Sunburst visualization or the hourly updated widget sitting in the background of participants' smartphone displays. In several cases, these experiences triggered participants to prospectively envision alternative kinds of interactions that could support such discoveries which are not well supported by current digital photo applications.

4.2 Experiencing and Reflecting on the Shifts between Different Timeframes

During our study, participants frequently made use of the pacing modes and selection filters to view their photos from different perspectives. When asked to compare her experiences with the three temporal lengths, **Rebecca** described a limitation in the finer granularities of Minute and Second modes:

> "With the Second and Minute, I feel like the granularity was finer than... I could realistically perceive. Hour made sense. Clearly, I go for morning walks around 9 to 10am. It was the timeframe and the granularity of the hour that I could see connections that I don't know if I would necessarily saw in the Second or the Minute mode. ...Part of me is like: 'Because time is a construct? And because we need to demarcate time in some way?' Maybe also because I don't plan my time in the second and minute way." (**Rebecca**)

In addition to the pacing control, PhotoClock enabled participants to apply selection filters of today's Date or Weekday to observe more specific life patterns in different timeframes. Overall, most participants considered that days of the week matter less whereas dates of the year were much more appreciated, as **Keith** shared in this quote:

> "Weekday was the weakest for me because I've had varying schedules over the years, so I didn't really see a pattern. Whereas the same date had the strongest effect. I can see all my history on the same date. Maybe it's in a different location, with different people. Also, age matters. In my case, it will be just 23 times at max that has happened, so it becomes very special. Same reason for why birthdays and new years are special. There's a lot of interesting interpretations and inferences to make from that." (**Keith**)

However, one exception exists because there was an extremely important life event tied to a specific weekday in work. This opinion was best depicted in **Sasha**'s case about an awakened feeling of her first day at work:

> "The only time I did feel [the importance of weekdays] was when I first entered the office in my previous company, I really liked the feeling [of seeing the office], so I took a picture during a tour. Basically, that particular day was a nice Wednesday. I still felt like all of this is just like yesterday. . . .But I think the Date [filter] made more sense to me, because that tells me how many years have passed and how time was moving so fast." (**Sasha**)

When reflecting on his experiences of using the filters on PhotoClock, **James** discussed how its minimal controls enabled him to recollect memories through 'a flow of pictures'.

> "On-demand control is a bit overwhelming since there are so many photos and it's sometimes hard to find specific memories. Having 'a flow of pictures' allows [me] to unearth some of those lost memories. For the latter, I like the grounding it gives you in terms of time and dates, whereas the former is only becoming manageable through AI sorting and labelling. Having more control is definitely a plus for the user experience, but given the vast amount of photos, rekindling memories is more about the randomness of finding pictures, especially when we might not even know that certain pictures existed in the first place." (**James**)

Collectively, through the interactivity provided by PhotoClock, participants were able to observe their life patterns more specifically on a designated date or day of the week. PhotoClock offered opportunities to revisit memories from our participants' respective digital photo archives in ways they largely did not have access to previously. Next, we describe participants' concluding reflection on their cumulative experiences of using PhotoClock at the end of our field study.

4.2.1 Accumulating and Reliving Memories through Ongoing Connections of Past and the Present. Following HCI research that calls for supporting people in wayfaring through their data from diverse perspectives [25, 75], PhotoClock offers an alternative way of revisiting one's life episodes through digital photo history. We found participants did not perceive PhotoClock as 'competing' with their existing practices or replacing their own photo library, but rather extending it a novel, memory-oriented approach to re-experiencing their archive. For example, consider **Natalie's** reflection on the memory-oriented experiences that PhotoClock provoked and how such an approach may exist harmoniously with existing photo viewing techniques:

> "The gallery view is almost irreplaceable at this point. It's an essential that we can control what photos to see. Whereas PhotoClock is more about not having control or little control, so you're in a more passive position to think about emotions. Honestly, I really like this because they are memories. When you think about memories, a lot of the times we look at things or hear things that trigger them. I don't recall the times where I actively searched for memory. It's usually being recalled unconsciously. . . .Each of these photos [on PhotoClock] brought me back to the state of mind and location I was in at the time. . . .Overall, it's very nostalgic and made me really appreciate my life. I feel grateful that I could go to these places, meet people, and document these photos." (**Natalie**)

Interestingly, **Timothy** reflected deeper on his experiences of conceptualizing time and memories among the three paces. He wondered whether there would be a potential temporal design for future digital technologies to make certain cyclical rhythms off in order to best provoke and support people's reflection on their day-to-day lives:

> "Time systems are so important in our lives. If we change that, it's like we're living on another planet. Imagine we only have 10 hours a day. That will totally change the way humans live, work and play. In Mayan cultures, there are 18 months in a year, and like 20 days in each month. . . .Sometimes I remind myself of having 1,440 minutes in a day, so I have more than 1,400 occasions to reflect and appreciate happiness. Different systems of time or timing really calibrate different mindsets. There might be a system that can 'optimize' reflection. I don't know what it is, but it does play an important part in nudging people to reflect and being appreciative of living, and living in the moment." (**Timothy**)

Towards the end of our study, it became common for participants to prospectively contemplate their photo archives from a longer-term perspective after using PhotoClock. Here, **Walter** considers what kind of digital photo archive he might possess in the future:

> "[Checking PhotoClock] There's no photos during this period on January 5, which means I've never taken a photo from two minutes ago. It's blurry in front of me right now. It is interesting to think about if we're way older in 20 years, how many photos we're gonna have? It's pretty interesting to think about this sort of emptiness. Like, unknown space in your life? Being filled or accumulated over time." (**Walter**)

On PhotoClock, perhaps one of the most fascinating things is to observe the changing relationship between participants and their loved ones. **Lori** specifically touched upon this topic:

> "Using PhotoClock is very counter-intuitive. Especially nowadays, you want to see everything immediately, so waiting has become more challenging. I really liked that. It's a rare experience in modern life. . . .PhotoClock reminds me of my relationships with others. ...For example, a travel experience, or a beautiful time with someone would make me print the screen and share with my friends. . . .This kind of passive photo viewing way provides me another chance to expect, which photo will jump out when I turn on my PhotoClock? It's always a surprise. . . .I will keep the app on my device if it keeps updated after the study." (**Lori**)

Regarding how PhotoClock enabled deeper reflection on a changing relationship with others, **Pamela** shared a touching story of remembering her loved one's past life patterns through a photo she had not visited for a long time:

> "I traveled [back] two weeks ago because my grandma passed away. During that trip, I saw one photo of my grandma's garden. I was missing her a lot. I'm glad I still have some of her photos in my albums, so it randomly pops up. That photo has been in my album for more than five years. Yet, it's until the day I saw it that I realized it was actually [around] sunset. PhotoClock reminds me of a daily thing that my grandma used to do. When she was alive, she would go up to the garden and water her plants. It's usually 4 or 5pm. That's also the time she worshiped God. Her garden is on the fourth floor of the house. My grandma couldn't go up there in recent years, so she just asked someone to help her. It's too many stairs to climb. So, it's her routine — every day in the morning, and before sunset." (**Pamela**)

Keith noted his appreciation of PhotoClock for how it supported him in celebrating precious moments through a unique 'abstraction of time':

> "There is value in just associating yourself with the rough time of a previous moment. You don't actually need to know the exact numeric value behind it. Even with Spotify's wrapped [a review of songs the user have listened to throughout the year], . . .they don't really need to tell you that you heard the song in this day in time. I feel like the more information you give, it reduces its significance. But grouping it together is what makes you see a pattern. When you take away the numbers and the actual individuality of it, it becomes a pattern of things. Like PhotoClock groups your photos in a very unique way, in an hourly lens. It does invoke that feeling of making you celebrate previous precious moments. And people do share the moments because they enjoy nostalgia and appreciate their experiences." (**Keith**)

Collectively, through the PhotoClock interaction design, participants rediscovered their digital photo archives in a more experience-centered way. These findings illustrate the potential value in supporting alternative ways for people to journey through their vast and still growing digital photo archives. To this end, they make clear that the long-term nature tied to the digital photo accumulation that people now experience should be treated with reverence when designing digital photographic technologies – which we reflect on more deeply next.

5 DISCUSSION AND IMPLICATION

Interacting with digital photos shapes how people locate, retrieve, recollect, and share memories. Our findings validate and extend prior work ([4,9,68,89]) by showing that current technology often complicates and limits these practices. Our research offers key contributions that advance current research in the following ways:

- Using clock time and timestamps as design materials to invite flow-based exploration into one's digital photo archive;
- Providing minimal controls to support people's interaction with their life history hidden in personal data over time;
- Extending the conceptual lens of slow technology through developing diverse strategies to design with temporality.

Next, we discuss opportunities and challenges for future HCI research tied to these points.

5.1 Flow-based Interaction Design for Memory-oriented Photo Viewing Experiences

Previous studies show that photos are valuable media that trigger people's recollection and interpretation of their autobiographical memories [5, 6, 44]. Targeting people's longer-term engagement with their large and growing personal photo archive, our approach minimizes navigation controls for photo exploration and foregrounds focus on the ongoing passage of time and the memories that may be bound to present moments. Our findings suggest that through the accumulation of such reflective moments, PhotoClock was validated as a viable dynamic approach to mediate interactions with digital photos, named as 'flows' by **Walter** and **James**. Through our study, it became clear that this continuous form of experience highly depends on the connection between the ongoing 'now' and all of the memories tied around the same time of day in the past. Interestingly, this kind of temporally dynamic flow-based process of remembering the past invited a range of photo viewing experiences that included curiosity, anticipation, nostalgia, and reflection. According to **Natalie**, the PhotoClock interaction design resembles the way memories are usually recalled organically—through unintentional, incidental, or serendipitous moments as opposed to proactive search. This finding supports van den Hoven et al.'s research, where they found: "everyday personal memories and cues are often not controlled in any way, at times the cues are not even presented explicitly" [45, p.113]. In extending this work, we found that PhotoClock primed participants with a reflective mindset where they not only made sense of their photos as a collective whole of their life history but also perceived photo viewing in a take-it-or-leave-it approach, where memories could be ephemeral. They come and go naturally, following the flow of time.

Our study of PhotoClock revealed three key critical factors that shaped participants' flow-based remembering processes: *ambient representation*, *consecutive triggers*, and *minimal controls*. First, the use of a persistent yet unobtrusive *widget* as a dynamic ambient window into one's photo archive resurfaced participants' photos through a subtle expression. Unlike the well-known interruptive nature of common mobile notifications that have and continue to trouble people (such as sound, badge, and alert) [26, 50, 88], the PhotoClock widget functions independently at its own pace, which our participants widely valued. Second, we presented *a series of instances interrelated to each other* as time goes by. The process of accumulating visual information supported participants to slowly recontextualize their memories from various camera angles, as depicted in **Keith**'s quote. Here, those normally considered 'bad' shots or duplicate photos within people's archives could operate as unique resources for remembering the situated context of memories differently. Third, our findings show that the *minimal controls* allowed in PhotoClock put participants in a constructively 'accepting' or 'passive' mindset, where they were able to let go of control, receive a photo from their past, and reconstruct their autobiographic memories in a self-determined and ongoing way.

Collectively, the integration of our design decisions offers a novel way of engaging people in rediscovering their trajectory of life journeys and cyclical patterns over time, which, they did not have easy or intuitive access to within their digital photo archives. Yet, clearly there is an opportunity for future research to make use of other digital forms to enable flow-based interaction. For instance, similar to widgets, smart watch faces might work as an effective ambient form to resurface one's photo memories over time. Likewise, alternative digital formats that represent one's personal history, such as videos, live photos, and blended media forms like audio and photo (e.g., Slide2Remember [48]), are also worth investigating because, unlike regular static photo files, they require time to fully reveals themselves. Thus, these media forms could be natural materials for flow-based interaction design to offer more diverse perspectives of one's life journeys. Future research in this space will be important for all, but perhaps most critical for the younger generation as they have started to create and develop a multimedia library as a way to represent their life history and to share it with others (e.g., [38] and **Keith**'s emerging accumulation of video memories).

5.2 Minimal Controls in Supporting Longer-Term Human-Data Relations

While prior research suggests that more forms of control and direct manipulation are needed to engage people in the digital photographic practices [3, 8], our findings offer a generative and constructive counter-narrative that illustrates how *minimal controls* can provide pathways for people to focus and reflect on their memories in a dynamic way that may change over time. According to Axtell et al. [3], the combined lack of *user control*, lack of *visual context*, and *manual curation* are key reasons that photo viewing applications (e.g., slideshows, large scrolling galleries, and tabletop) are often not effective prompts for remembering the past or for spontaneous reminiscence. Taking an alternative approach, our study of PhotoClock offers a design case that productively invited participants to reflect on unexpected elements within their digital photo history with minimal controls. This led to our participants adopting a largely open mindset where they focused on the photo presented in the present moment, and the associations that might emerge between the now and the past. Taking **Pamela**'s photo of her grandma's garden as an example, PhotoClock enabled her to rediscover this photo and her loved one's life patterns for purposes of mourning and peacefully dealing with grief.

Yet, we also found one apparent and important limitation in the PhotoClock design is its restriction of how long participants could interact with each selected photo. While appreciating their life patterns being depicted by the temporal flow and empty moments, participants desired ways to modulate the photo viewing pace more flexibly, perhaps especially when there were unexpected and uncomfortable interaction 'gaps'. For instance, **Melissa** reported a frustration in Minute mode that she experienced her eagerness to know what the next photo would be for almost an entire minute after she had processed a photo. Thus, a clear implication following from our research is that it is important to build in support for manual and flexible tuning interaction pacing with somewhat minimal controls, such as a refresh feature enabled only within the longer pacing modes like Minute and Hour. For example, at 12:33:00pm, a user sees a new photo on PhotoClock and starts a process of recontextualizing and reflecting on the

memory. At 12:33:21pm, they have concluded the process and could decide whether or not to receive another photo that was also taken at 12:33pm in Minute mode (or another photo taken at 12:00-12:59pm in Hour mode). Alternatively, there could be a fast forwarding and rewinding feature that allows people to drift the photo viewing pacing in and out of alignment with common rhythms of second, minute or hour (e.g., the photo transitions every 12 seconds).

In sum, the approach of designing with minimal controls has shown its value to support people's longer-term relationship with their data and digital possessions. It implies opportunities for future research to investigate how temporal trajectories of one's data might be dynamically preserved and revisited as they accumulate over time. Such interaction could give rise to memory-oriented experiences that offer unique comparisons and entanglements of life histories throughout one's archives or among a group of people for social interactions. As opposed to using on-demand controls overwhelmingly (e.g., AI sorting and keyword searching), **James** argued that memories were better rekindled in a flow of photos naturally using minimal controls, especially when he did not know what was in his vast digital photo archives in the first place. Echoing this view, we argue that having more ways of providing 'some temporal context' should be further investigated as hints to prime and enrich people's interpretations of their own memories. This design-led approach can be seen in complement and in parallel to more technically driven approaches to photo organization and interaction (e.g., machine learning and information retrieval).

5.3 Temporal Metadata as a Design Resource for Discovering Personal Empty Moments and Life Patterns

Building on prior research that have investigated the use of photos as memory cues to invite reflection [77, 80], our study of PhotoClock has advanced a novel technique of using temporal metadata to trigger memories. This approach led to 'empty moments' playing important roles in supporting participants to discover different forms of remembering and to speculate what would be filled in their own photo history 'gaps.' For example, **Sasha** mentioned that it was the empty moments she perceived in PhotoClock that gave prominence to her own life patterns and made her curious. Similarly, **Walter** experienced his empty moments on January 5th and wondered what photos could be there if he launches his PhotoClock 20 years later. Taken together, those 'temporal blanks' in periods when one did not take any photos in their life created room for participants to make rich interpretation and inference from them. They also stand as an alternative design resource that future work can mobilize within new photo viewing applications, as well as in approaches to *data wayfaring* [25, 75] where people navigate their lived experience through using a variety of personal data.

However, our application of gradational blurriness is simply one way of representing empty moments. There exist opportunities to extend a research focus from investigating empty moments or gaps in one's data history to exploring how more diverse conceptualizations of empty moments could support people to understand and interact with their digital possessions. For instance, future researchers could apply different rhythms of pause (e.g., [27]) when giving form to empty moments or 'creating' empty moments. An example of applying a '*pending*' form of pause to empty moments in PhotoClock is to show people what scene their phone's rear-facing camera is currently capturing instead of a blurry version of the upcoming photo. If the user likes the scene, they can press a shutter button in app to merge it into their personal photo history immediately. This way visualizes a process of transferring one empty moment from a pending scene into an actual photo instance. Another example could be to apply a more '*periodic*' form of pause in PhotoClock, where **Pamela** could set up a recurring event on her grandma's death day and only see her grandma's photos on that date every year. The originally occupied time stacks of her grandma's photos could then focus on presenting her other photos or any new photo she takes in the future. Of course, this design approach would have to be handled carefully through properly safeguarding the ability of users to opt in and out of such intimate and sensitive temporally recurrent photo rituals.

Collectively, these opportunities come together to highlight a critical need for future research to explore how technologies could mobilize and express more diverse forms of time to support people's understanding of their precious previous moments. Through studying empty moments, more design opportunities could be discovered to support people's exploration of personal life patterns as well as the creation of their anticipative future moments through and across time.

6 CONCLUSION, LIMITATIONS, AND FUTURE WORK

Through designing PhotoClock and studying it in the field, we explored clock time as an element of temporal ongoingness raised by slow technology and investigated how this framing could offer a generative lens to support memory-oriented interactions with personal digital photo archives. It is important to recognize our study is not without limitations. In terms of limitation, we focused on a smaller set of participants that currently live within North American contexts and utilize iOS devices, with the majority of them being women and Asian. Clearly there is a need for future research to expand to other populations on social, cultural, and technical dimensions. Our findings do provide new insights into how mobilizing interconnected temporal modalities can offer unique ways of interacting with digital photo archives that overcome the limitation commonly found in contemporary photo viewing applications, which inhibit users' recollection of experiences. They also detail how present moments, digital photos, and interaction can come together in a design artifact to evoke a quality of co-evolving change over time. Our research contributes another step toward understanding how the concept of slow technology can be extended and advanced in design practice and field research. This work also contributes to calls in the HCI community for longer-term programs of design research. Ultimately, we hope this research supports future work inquiring into the role, place, and pace of digital data in everyday life, over time and into the future.

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