Exploring temporality for digital photo wayfaring

by

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Abstract

Since the 19th century, photographs have supported people's practices of self-reflection, social interaction, and contemplation of the future. Today, digital photographic technologies have enabled people to create a massive proliferation of photos at scales larger than ever before. This technological advancement allows people to accumulate more precise and extensive personal memories in life. Yet, it also poses new challenges. For example, digital photos become formless, lacking the material presence as a reminder of the existence and content of people's archives. To address these challenges, new approaches are needed for people to engage with their digital photos.

My dissertation contributes to three research goals. First, I inquire into how making people's digital photo archives more present and interactive through a temporal lens might open new possibilities for reflective memory-oriented photo viewing; in this, I attend to how photos work as cues that trigger autobiographical memory. Second, I investigate how temporal metadata could operate as a resource for generating a renewed sense of awareness and control over large and still growing digital photo archives. Third, I pursue personal life history as an accumulating and prominent aspect of time to design technologies for reflection.

My overarching research question is: How can memory-oriented experiences with personal digital photos be supported and sustained as they grow, expand, and age over time? To answer this question, I adopted *research through design* as the primary methodology and created two design cases. First, *Chronoscope* is a tangible photo viewer that displays photos in chronological and non-chronological expressions of time. Second, *PhotoClock* is a mobile application that uses the current clock-time of the present moment to re-present photos taken around that same time of the day in one's past. These design cases were investigated by combining a practice-based *designer-researcher approach* with *research product* field deployment studies.

Building on these works' findings, the end of this cumulative dissertation discusses how an *artifact analysis* could mobilize and extend a theory of slow technology. Ultimately, this dissertation showcases the importance of investigating temporal modalities to support people to interact with their digital photo archives as contributions to future HCI research and practices.

Keywords: temporality; slow technology; digital photos; interaction design; human-computer interaction; research through design

Dedication

To Judy Mei-Feng Lin and Sam Shih-Shuen Chen, for that you are the grandparents of this dissertation. Thank you for daring to make countless life decisions, whether significant or trivial, joyful or challenging, that have embraced and shaped a rebellious girl into the person she is now and will be in the future.

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Each of my publications were collaborations with one or more researchers. Here I detail the roles of each researcher.

> Amy Yo Sue Chen, William Odom, Ce Zhong, Henry Lin, and Tal Amram. 2019. Chronoscope: Designing Temporally Diverse Interactions with Personal Digital Photo Collections. In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19), ACM, New York, NY, USA, 799–812.

For this paper, I started the research idea, created the initial form, did the electronics design, wrote the programs in Python, designed the study methods, conducted the data collection and analysis, and wrote the paper. Dr. Odom contributed to the idea development, provided feedback in the design process, and worked with me to edit the final version of the paper. Ce Zhong worked on the 3D modeling and 3D printing of the final form. Henry Lin provided feedback on the 3D printing process and the electronics design, and supported the 3D printing and painting of the artifact. Tal Amram supported the idea development and suggested potential options for the electronics design.

> Amy Yo Sue Chen and William Odom. 2021. Crafting temporality in design: Introducing a designer-researcher approach through the creation of Chronoscope. In The Routledge International Handbook of Practice-Based Research. Routledge, 368–380.

For this book chapter, both Dr. Odom and I reflected deeply on what our designer-researcher approach is. I created the content structure and wrote this chapter. Dr. Odom contributed to the content development, provided feedback in the writing process, and worked with me to edit the final version of the paper.

> Amy Yo Sue Chen, William Odom, Carman Neustaedter, Ce Zhong, and Henry Lin. (2023). Exploring Memory-Oriented Interactions with Digital Photos In and Across Time: A Field Study of Chronoscope. In Proceedings of SIGCHI Conference on Human Factors in Computing Systems. Hamburg, Germany, CHI'23. ACM Press.

For this paper, I enhanced the artifact quality and robustness of Chronoscope, designed the study methods, conducted the data collection and analysis, and wrote the paper. Dr.

Odom contributed to the data collection and analysis, and worked with me to edit the final version of the paper. Dr. Neustaedter provided feedback on the paper writing process. Ce Zhong produced images of the 3D modeling form and assisted in the data collection process. Henry Lin facilitated the 3D printing process, enhanced the electronics design, and did the photo shooting of the artifact.

> Amy Yo Sue Chen, William Odom, Sol Kang, and Carman Neustaedter. 2023. PhotoClock: Reliving Memories in Digital Photos as the Clock Ticks in the Present Moment. In Proceedings of the 2023 ACM Designing Interactive Systems Conference (DIS'23), Association for Computing Machinery, New York, NY, USA, 1015–1031.

For this paper, I started the research idea, created the prototypes, wrote the programs in Swift, designed the study methods, conducted the data collection and analysis, and wrote the paper. Dr. Odom contributed to the idea development, provided feedback in the design process, and worked with me to edit the final version of the paper. Dr. Neustaedter provided feedback on the paper writing process. Sol Kang supported the data collection and analysis and the paper writing process.

> William Odom, Erik Stolterman, and Amy Yo Sue Chen. 2022. Extending a Theory of Slow Technology for Design through Artifact Analysis. Human–Computer Interaction 37, 2, 150–179.

For this journal article, Dr. Odom and Dr. Stolterman started the idea of conducting an artifact analysis on a series of slow technology artifacts for the development of slow technology design strategy. Dr. Odom did most of the writing. My role is to offer two design cases that I own, provided the images, and supported the article writing and editing process.

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List of Acronyms

HCI	Human-Computer Interaction
RtD	Research through Design
SFU	Simon Fraser University

Chapter 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 [38]. 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 [24].

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 [161,170,215]. This tension can create barriers for people to gauge how big their archive is and, consequently, revisit experiences, histories, and impressions captured within them [170,245]. 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 [15]. 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., [31,54,95,162,223]). 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" [136:11]. 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.

To support the exploration in this research space, slow technology stands as a promising design strategy that could be applied and extended at the same time. In 2001, Hallnäs and Redström proposed slow technology as "*a design agenda for technology aimed at reflection and moments of mental rest rather than efficiency in performance*" [85]. Since then, numerous research works have applied a delayed timing of interaction to enforce a slow pacing for reflection [32,160,162,174,223]. However, as opposed to a simply delayed expression [222], a small but growing number of researchers have recently turned to discuss alternative conceptualizations of time. For instance, a design case named CrescendoMessage was created to explore how sending messages in the near future supported people's reflection on messaging and communication with others [222]. *Rhythms of pause* were investigated in the multi-lifespan design of information systems for transitional justice [64]. In 2015, Lindley proposed a view to examining the notion that people's everyday life has been accelerated by both their conceptual and practical adoption of *clock time* [126]. The temporal properties of physical materials such as *decay* and *patination* are also explored through the study within the HCI field (e.g., [224]). In parallel, Pschetz and Bastian make a compelling argument that it is essential for interaction design research to inquire into generating new possibilities for people to perceive and consider multiple temporalities [181]. Albeit from a different perspective, this argument resonates with Huang and Stolterman's work that emphasizes awareness and analysis of temporality [101]. Collectively, these works have shown that the form and expression of temporality have received considerable attention and given rise to topics of: **(i) whether the interactive pace of a technology should be designed in a way that is either literally fast (for efficiency) or slow (for reflection)**, and **(ii) what alternative forms of temporality exist to support, extend, and explore everyday reflection and mental rest in longer-term human-data relations**.

Motivated by the set of challenges mentioned above, this dissertation contributes specifically to this intersection through investigating 3 key research objectives. First, I inquired into how making people's digital photo archives more present and interactive through a temporal lens might open new possibilities for situated, reflective memory-oriented photo viewing; in this, I attend to how photos work as cues that trigger

autobiographical memory. Second, I investigate 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, I pursue personal life history as an aspect of temporality raised by *slow technology* [85,163] and explore how this framing might offer a rich way to support ongoing and indeterminate experiences with digital photo archives that grow over time. To achieve these research goals, I have developed my research questions and approaches in the following section.

1.1. Research questions and approaches

The overarching research question of my thesis is:

How can memory-oriented experiences with personal digital photos be supported and sustained as digital photo archives grow, expand, and age over time?

To investigate this question, I adopted *research through design* (RtD) [46] as the primary methodology. RtD is a common and useful approach to generate answers to qualitative research questions that investigate potential futures in a grounded, practice-based way. Importantly, this approach does not provide a single answer or an absolute solution. Instead, RtD results in a real creation that ground theoretical concepts. It produces design exemplars for researchers to understand people's situated experiences interacting with real and working systems over time. The insights generated through RtD can also support the advancement of design theory as contribution for future interaction designers and researchers to take into consideration.

I started my RtD inquiry by studying a great number of prior works in relation to digital photo viewing experiences and personal data. Projects such as Pensieve [174], Olly [166], and Olo Radio [158] show that temporal metadata could be a generative design material for reorganizing one's digital archives and enabling new reflective experiences. Since temporal metadata had not been widely explored as a design material within the digital photo research space, I decided to have my first research project ground it in design practice and create a design exemplar through a critical and in-depth design research process. Thus, I proposed the following research question for my initial dissertation research:

RQ1: What opportunities exist to leverage 'temporal metadata' as a design resource that supports memory-oriented ways of experiencing the trajectory of digital photos one has accumulated in their life?

To address this research question, my objective was to conduct a practice-based design research study to explore alternative ways of using temporal metadata as a design material that enables people to view their digital photo archives as a whole. This design research inquiry eventually led to the creation of a tangible photo viewer named *Chronoscope*, a domestic technology that leverages temporal metadata embedded in digital photos as a resource to encourage more temporally diverse, rich, and open-ended experiences when re-visiting one's personal digital photo archive. It reorganizes one's photos based on when each photo was taken, so its user can view their photos in a chronological or non-chronological sequence. (See more details in Chapter 3)

Figure 1: Chronoscope is a tangible photo viewer that allows its user to view their photos in and across time.

The resulting creation emerging from this practice-based design research supported our research team to advance our understanding of temporal metadata as a design material in the context of human-photo interaction. Through interacting with Chronoscope, we found two tensions in the photo viewing process. First, the sheer size of digital photo archives could easily leave users *stuck in time* – it could require days of continuous rotations simply to navigate through all of one's digital photos if one photo or a few advanced per one rotation. To cope with this issue, we created a design feature that allows users to move through multiple photos per one rotation. Yet, this introduced another challenge. If the upper threshold was too high (e.g., 1,000 photos), then a user

could easily become *lost in time* as users navigated a large amount of photo in one turn. Through these tensions, we found a slow technology design quality named *temporal granularity*, which is to provide a flexible control of tuning how many photos would be viewed in one step of interaction. This quality could be used in a design of technology to resolve the *lost-in-time* and *stuck-in-time* tensions that people may encounter when exploring their vast and still growing digital archives. This design study is published as:

> Amy Yo Sue Chen, William Odom, Ce Zhong, Henry Lin, and Tal Amram. 2019. Chronoscope: Designing Temporally Diverse Interactions with Personal Digital Photo Collections. In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19), ACM, New York, NY, USA, 799–812.

Building on this work, I reflected on the Chronoscope design research process more deeply through a methodological perspective. It was during this thinking process that my second research question emerged:

RQ2: What are viable conceptual frameworks for conducting practice-based design research that utilize notions of time to invite one's reflection on their vast and still growing digital photos?

For this question, in collaboration with my supervisor, I led the writing of a book chapter in a research handbook for a broader audience of practice-based researchers and practitioners. We critically reflected on what design philosophies and approaches had highly impacted how we think and make design decisions throughout a design-led process. This publication gives a sense of what our research team's particular designer-researcher approach is and position this approach among existing practice-based research methods or concepts in the design research field:

> Amy Yo Sue Chen and William Odom. 2021. Crafting temporality in design: Introducing a designer-researcher approach through the creation of Chronoscope. In The Routledge International Handbook of Practice-Based Research. Routledge, 368–380.

This book chapter supported me to think through how our piecemeal designer-researcher approach led to the final version of Chronoscope artifact (See more details in Chapter 4). Through unpacking this designer-researcher approach, we started to see Chronoscope as a slow technology design case that offers a high degree of user control while retaining design qualities that are closely tied to the original conceptual vision of

slow technology. We would not have arrived at Chronoscope's final version and the insights in relation to temporal granularity without the piecemeal, iterative, and first-person practice-based design approach. However, despite the benefits and opportunities of this approach, the research outcome is still limited to our own experiences of using Chronoscope in the design team. To better understand people's situated experiences of Chronoscope, we were inspired to conduct an empirical study. We decided to create and deploy a batch of 4 Chronoscope research products to 4 participants' houses for 3 months in order to collect people's longer-term lived experiences with Chronoscope in field. The research question that is investigated through this field study is:

RQ3: What memory-oriented photo viewing experiences could be supported and sustained through a tangible photo viewer that allows people to explore their digital photos chronologically and non-chronologically?

The collected data was then analyzed, discussed, and published as:

> Amy Yo Sue Chen, William Odom, Carman Neustaedter, Ce Zhong, and Henry Lin. (2023). Exploring Memory-Oriented Interactions with Digital Photos In and Across Time: A Field Study of Chronoscope. In Proceedings of SIGCHI Conference on Human Factors in Computing Systems. Hamburg, Germany, CHI'23. ACM Press.

Through this deployment study, we learned that participants valued the *journey-based* photo viewing experience enabled by Chronoscope's interaction design. Targeting people's relationship with their entire photo archive, our approach extends control over different temporal modalities to navigate unique pathways through multiple memories and life stages. These pathways opened new ways of mediating interactions with digital photos which participants characterized as 'journeys' across their life experiences. We found people valued this form of journey-based photo interaction when it resurfaced forgotten or unknown life patterns, especially those in less familiar modes. Because it is not easy to anticipate what photos would be interconnected in less familiar modes, people can revisit, associate, and reflect on multiple surprising moments at once in their exploration journey, triggering a provocative way of integrating and interpreting autobiographical memories. Through our study of Chronoscope, we offer a design case of using temporal metadata as a memory cue to trigger a journey-based remembering process that brings more curiosity, anticipation, and refection into the process of digital photo wayfaring. However, one limitation of using temporal metadata as a memory cue

is that geo-locational metadata and calendrical metadata are needed if one's photo memories were taken or associated with different time zones and calendar systems (See more details in Chapter 5).

Based on the findings in our deployment study of Chronoscope, we discovered design opportunities in relation to interaction pacing, user control, and timing. We first discovered an interesting notion called *temporal blanks*. Chronoscope has one limitation in that it connects photos in a sequence that entirely hides the 'blanks' or 'gaps' in periods when one did not take any photos in their life. Our research team considered that this kind of temporal blanks in one's photo archive may hold important meaning in one's life history, such as intentional removal of key life experience (e.g., due to a romantic breakup, loss of a loved one etc.). Second, we became interested in providing fewer user controls for people to engage with their entire digital photo archives. Chronoscope provides multiple sophisticated user controls (viewing directions, timeframe modes, and temporal granularity). While these controls supported participants to flexibly explore their photos in and across time, they took time for people to fully understand how it works and made the photo viewing process quite proactive and intentional. Thus, both the notion of temporal blanks and the design of user controls prompted the question: How do people perceive temporal blanks in their digital photo history? How does user control affect the ways people reflect on their photos? And ultimately, what does it mean for one to view their digital photo archives as a whole? These thoughts led me to connect my research path to a concept named *wayfaring*, which Rooksby et al. discussed in their CHI 2014 paper. In the field of personal lived informatics, they articulated this concept with a vision:

> "When people track their activities (when they dwell in data) they are not building a description of their lives, but are wayfaring in information. To know ourselves is not to look at the past or even to the present, but to the future. …one is not following a set path to one's imagined future but is navigating using a variety of information, cues and intuitions as best one can. Knowing oneself may involve collecting and reflecting on information about oneself but is for the purposes of a life being lived." [189:1171]

This way of seeing the reasons why people preserve and cherish their personal data resonates with my own view on why people desire more enriched experiences with their digital possessions. For this, I recalibrated my thoughts and considered my research goal to enrich digital photo wayfaring experiences through multiple temporal lenses.

To brainstorm ideas for digital photo wayfaring, I engaged in a critical-reflexive design process similar to how I arrived at Chronoscope. Through iteratively generating design ideas and critically assessing them by potential research questions about time and slow technology, I progressively narrowed the ideas down to a core concept in relation to the perpetual movement of time. This core concept applies the current clock time to constantly tie the present moment to one's past by presenting photos that were taken at 'this time of day' in the past. This constant connection between the past and the present is designed to create a sense of ongoingness and intimacy between one and their past selves. Motivated by this concept and how it could affect people's lived experiences with their digital photos, I proposed my fourth research question:

RQ4: What opportunities exist to leverage 'current clock time' as a design resource that supports new ways of experiencing the trajectory of digital photos one has accumulated in their life?

To investigate this question, I created the second main design case in my dissertation research called PhotoClock, a mobile application that leverages the creation date and time embedded in digital photos to encourage contemplation of memories from the past bound up in one's photo archive. A key objective in the PhotoClock project is to explore how the perpetual movement of time can be leveraged as a unique resource to continually connect the present moment to people's photos taken around that same time of the day in the past. I aimed to investigate how people perceive their memories through digital photos that are displayed ephemerally, only around the clock time they were taken in the past. Through eight months of iteration in our RtD process, we arrived at the final version of PhotoClock, a design exemplar of leveraging the perpetual movement of time to enrich memory-oriented experiences (See more details in Chapter 6).

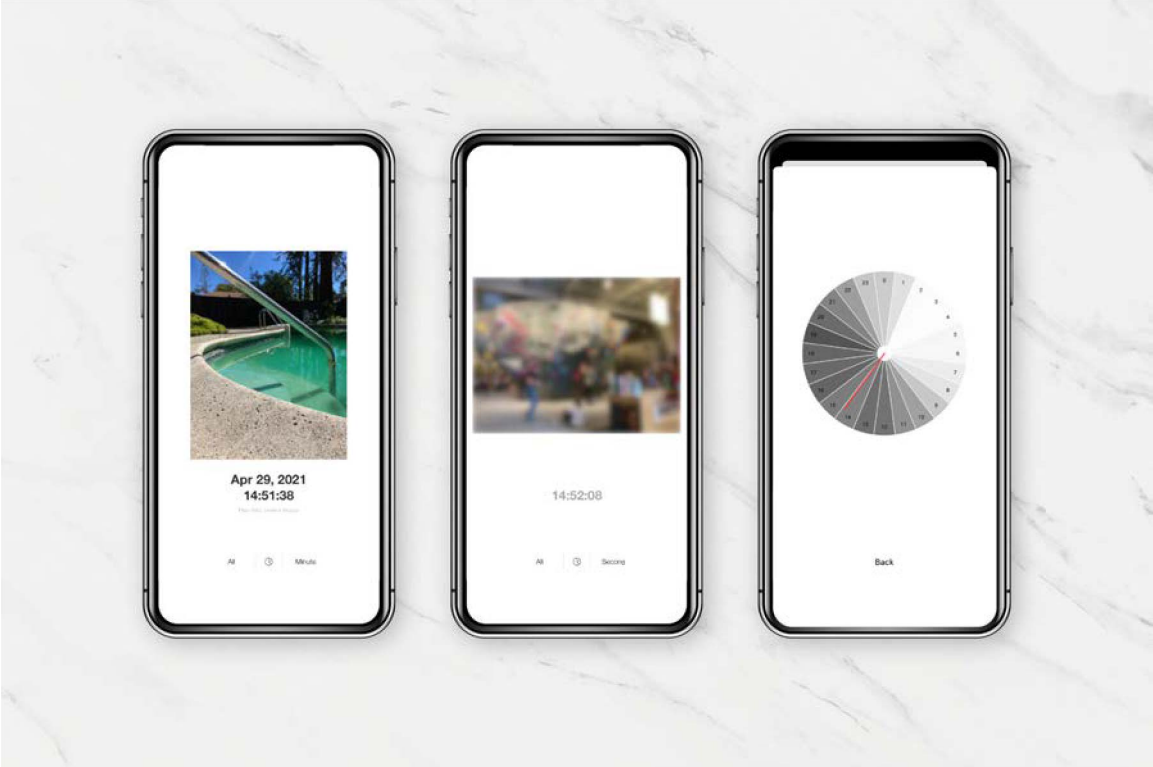

Figure 2: The user interface of PhotoClock.
***Left*:** The user sees a photo clearly with all the metadata presented in the page. ***Middle*:** In a special case, the user sees a blurry photo and it gets clearer as time goes by. ***Right*:** The user enters the Sunburst page and see how many photos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

Our research team recruited 12 participants to live with and experience this PhotoClock research product over an eight-week period through a field deployment study. This work is accepted by DIS 2023 and will be published as:

> Amy Yo Sue Chen, William Odom, Sol Kang, and Carman Neustaedter. 2023. PhotoClock: Reliving Memories in Digital Photos as the Clock Ticks in the Present Moment. In Proceedings of the 2023 ACM Designing Interactive Systems Conference (DIS'23), Association for Computing Machinery, New York, NY, USA, 1015–1031.

Findings from this field study show that PhotoClock's minimal controls created a *flow-based* photo viewing experience that supports participants to rediscover their trajectory of life journeys in a way where memories could be ephemeral. 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'. 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 participants, the PhotoClock interaction design resembles the way memories are usually recalled organically—through unintentional, incidental, or serendipitous moments as opposed to proactive search. 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.

In parallel to the PhotoClock project, my supervisor, an additional academic collaborator, and I collectively saw an opportunity to conduct an *artifact analysis* of a collection of slow technology design examples in order to extend a theory of slow technology. Artifact analysis is a method that performs analysis on a small set of design artifacts as a way to assess the stability of existing design theories. Artifact analysis can also support a discussion or an update of design qualities and reveal opportunities for developing new theoretical concepts. With an aim to assess the theory of slow technology, we included Chronoscope and other design cases in our artifact analysis. The research question that guided our analysis is:

RQ5: What opportunities exist to extend a theory of slow technology for interaction design through more diverse and expressive design qualities in relation to time?

My primary aim here is to investigate the intersection of slow technology, temporality, and digital photos. My secondary goal is to contribute more broadly to the development and extension of the original slow technology vision and enable the theory to be more robust and practically accessible to design practitioners and researchers**.** We reported the results of our artifact analysis to illustrate how slow technologies could be designed to invite reflection in a recently published journal article:

> William Odom, Erik Stolterman, and Amy Yo Sue Chen. 2022. Extending a Theory of Slow Technology for Design through Artifact Analysis. Human–Computer Interaction 37, 2, 150–179.

The theory of slow technology was originally outlined by Hallnäs & Redström in 2001 and where its vision was articulated through three core concepts: *reflective technology*,

time technology, and *amplified environments* [85]. In our work, we developed and refined eight design qualities through detailed artifact analysis of seven design artifacts that exemplify key aspects of the extended theory. Two of these design artifacts, Chronoscope and Crescendo Message, resulted directly from projects I have led. In my thesis, I contribute further to this artifact analysis by including PhotoClock within this collection of works and detail new theoretical insights that it reveals in light of our prior research (See more details in Chapter 7).

Ultimately, this dissertation showcases the importance of investigating temporality in interaction design and ways of applying time to support people's relationship with their vast and still growing digital archives (such as digital photos) as contributions for future HCI research and practices. The intended audiences of this work are HCI design researchers and practitioners who are interested in understanding more diverse approaches of creating new technologies that better support people's longer-term relationship with their digital photos, or with digital possessions in general. Another intended audience are HCI design researchers interested in advancing the design theory through a combined approach of practice-based and empirical design research. Secondary audiences may include researchers in the social sciences, humanities, and consumer behavior research fields that are interested in digital photos, memories, and people's perception of temporality.

1.2. Overview of chapters

Collectively, my 5 sub research questions and their following investigations have formed my cumulative dissertation which consists of 8 chapters:

Chapter 1 introduces the overarching research context and questions.

Chapter 2 is a literature review of this work's related fields.

Chapter 3 describes the practice-based design research process of Chronoscope.

Chapter 4 positions a designer-researcher approach within existing academic fields.

Chapter 5 describes the findings of the field deployment study Chronoscope research products.

Chapter 6 communicates the research through design process of making PhotoClock and the subsequent field deployment study of it.

Chapter 7 extends a theory of slow technology through design cases and qualities.

Chapter 8 concludes this dissertation with a critical reflection on its emerged challenges, opportunities, limitations, and implications for future work.

From Chapter 3 to Chapter 7, most of the content is adapted from my previous publications throughout the past 4 years in my doctoral study. At the end of Chapter 7, I have included an additional artifact analysis specifically on the PhotoClock project to further extend my contribution to this design theory project. Taken together, these chapters respond to my overarching research questions in a way that participants' memory-oriented experiences with their personal digital photo archives have been supported and sustained over time through a diversified use of temporal metadata that allows a creative reorganization of one's digital photos. At the end of this dissertation work, Chapter 8 described more design opportunities and challenges in relation to designing technologies with the temporal qualities produced from our artifact analysis. This dissertation concludes with a critical reflection on my accumulated investigations that have extended and applied a temporally enriched and diversified framing of slow technology for design. This critical reflection is provided with an aim to make a concrete research contribution to the HCI and interaction design field.

Chapter 2.

Literature Review

This section presents a synthesis of prior works in relation to digital photos, memory studies, personal data, and slow expression. These categories collectively point to research opportunities of creating alternative digital photo viewing systems that support people's memory-oriented experiences in their everyday lives.

2.1. Digital photo viewing experiences

Digital photographs have existed for decades and represent one of the most prevalent and extensive forms of digital possessions that people have. Thus, it is perhaps no surprise that digital photos have received considerable attention in the HCI community and, more broadly, the social sciences and humanities. Numerous researchers have described the varied roles digital photos play in supporting identity construction (e.g., [40,41,89,236]) self-growth (e.g., [39,131,234]), practices of personal and collective remembering [5,21,45,46,145,235], as well as developing a cohesive life story over time [6,92,93,197,198]. HCI researchers have also long been interested in how people's everyday interactions with digital photo capture, storage, and organization could be improved (e.g., [65,115,234,236]).

Despite the valuable and diverse resources that digital photo archives can offer, the exponential growth of digital photos has made it difficult for people to access and engage with their vast collections [22,245]. Recent research by Bergman et al. [15] has shown that the adoption of smartphone has only exacerbated these difficulties as the production and proliferation digital photos continues to expand. Research has also shown design strategies for navigating large archives commonly mobilized in contemporary photo applications, such as long scrolling galleries of photos, are not effective prompts for remembering past memories [22] (See Figure 3). Scrolling galleries require photos to be opened to full screen before they can be fully recognized, which interrupts the experiential flow of browsing, thus limiting the capacity for reminiscence [5]. Other common strategies, like digital slideshows, overcome this tension by displaying photos in higher resolution, but introduce different complications—showing

only one photo at a time can cause people to lose the narrative context across the photo set which limits person-centered and episodic forms of remembering [2,5]. Further, slideshows require a subset of photos to first be curated from a large collection which diminishes capacity for spontaneous and serendipitous remembering experiences [5]; and, more generally, people tend to abandon efforts to manually curate digital photos [15].

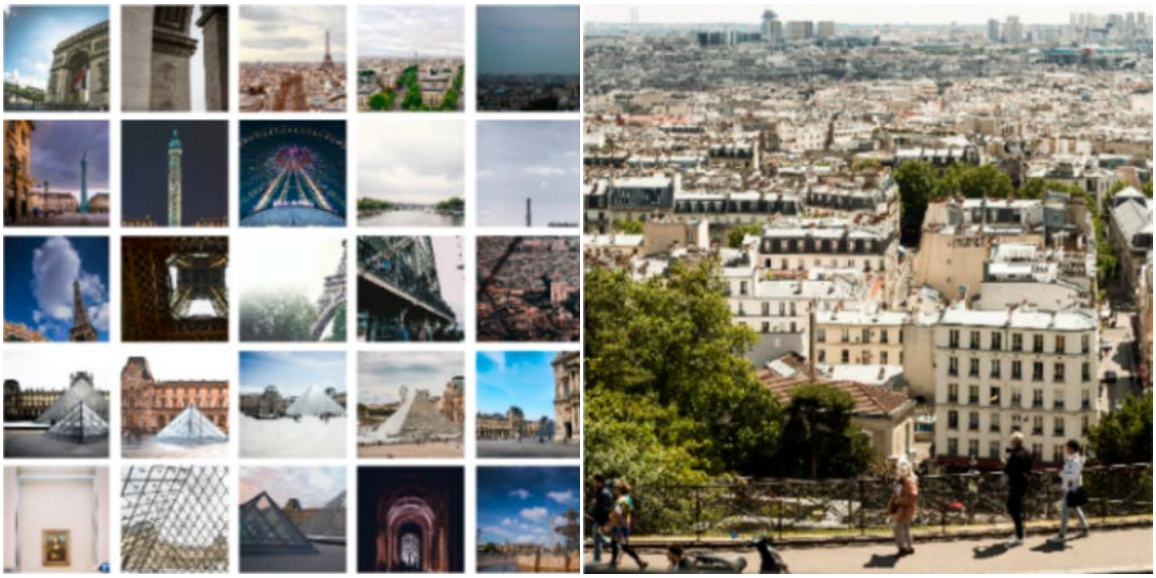

Figure 3: Common photo viewing interaction design: (1) Scrolling Gallery, and (2) Slideshow.
Images retrieved from Axtell et al.'s paper in 2022 [5]

Design researchers have begun to investigate strategies to address these complex tensions and better support interactions with people's photo archives that can scale over time. One key strand of research has focused on investigating how tangible interactions can be designed with personal digital photo archives [8,95,139,162,246]. A limited selection of design research projects, such as Photobox [162], ReFind [241], Memora [91], Photoswitch [52,53], and Fenestra [227], have shown the value of increasing the physical presence of digital photos in people's everyday lives through the creation of new design artifacts.

Figure 4: ***Fenestra*** **is a domestic technology embodied in the form of a wirelessly connected round mirror, photo frame, and candle that displays photos of departed loved ones.**
Images retrieved from Daisuke et al.'s paper in 2016 [227]

These works have begun to illustrate how the combined qualities of form, materials, and interaction can lead to increased interactions with and perceived value of their digital photo archives as well as with the design artifact itself. Yet, they only focused on resurfacing a single or a small subset of photos in people's life. Another major HCI research area has focused on how tangible interactions with digital photo archives can generate alternative ways to support open-ended experiences, such as locating and sharing memories with digital photos (e.g., [109,230]), catalyzing social conversations (e.g., [87,95,222]), and supporting both individual and social experiences of reminiscence and reflection (e.g., [162,174,222,228,246]).

Other more recent HCI research has focused on creating interaction technologies for digital photos which include AR-enabled tangible photo viewing [27,83], two-sided formats for digital photos [81], and novel approaches for supporting photo taking practices such as selfies (e.g., [105,221]). While most of this research focuses on use-cases involving individual photos or a small number of photos from the recent past, metadata has begun to be explored as a resource for augmenting human-photo interactions with added contextual factors. Tactics such as vote-based photo curation [249], environment-based remembering and searching techniques [97], and

multidimensional visualization of photo collections [102] have each been investigated to limited degrees, respectively. These investigations are largely motivated by a practical need to manage and organize digital photos. Yet, few works have explored how metadata, as a context provider, could be used to support more diverse forms of photo viewing and interaction.

Overall, these collective works indicate that, while limited, there is growing interest in exploring new and novel ways to engage people's digital photo viewing experience. They also show the real and complex frictions that come with massive personal digital photo archives, highlighting the need for a multiplicity of approaches that can enable people to get a grasp on their archives and re-experience the memories bound up within their archives. In my dissertation, I aim to extend these works by deploying and studying a novel system that supports rich, open-ended interactions with personal photo archives through and across time.

2.2. Memory cues for autobiographical memories

At the intersection of HCI and memory studies, photographs have been investigated as powerful memory cues for autobiographical memory. They are often considered as information resources that aid people in remembering and retrieving key contextual details of a memory tied to one's personal history [196,204]. Research investigating memory cues has increasingly gained purchase within interaction design, with a particular focus on *external memory cues* – "physical or digital cues in tangible embodiment with an internal effect on memory reconstruction" [100:110]. Often initiated by memory cues, autobiographical memory is "memory for the events of one's life …where considerations relating to self, emotion, goals, and personal meanings, all intersect" [34:103]. In contrast with autobiographical memories, a design research method named *design memoirs* have been developed with an aim to provoke curiosity about deeply felt and formative emotional experiences through a first-person practice-based design process [44]. Taking these concepts in mind, one's personal digital photos can be seen as an archive with a growing number of memory cues in it that support people in retrieving memories that, in part, construct their life history [99,143]. Most contemporary digital photo applications and storage services have been designed to support voluntary recall of autobiographical memories that "follow a controlled, strategic retrieval process" [16:279] which involves considerable amounts of intentional searching,

editing, and repurposing techniques for photos. Yet, involuntary autobiographical memories, such as seeing a picture with high school friends on a bedroom wall with no preceding attempt at memory retrieval, have been found equally frequent and important in supporting people's everyday remembering processes [192]. People's experience of remembering can be seen as a situated and constructive process [10], and tangible memory cues existing in people's living environments have been found highly effective in triggering involuntary autobiographical memories [16,99].

Against this backdrop, I aim to extend these works through investigating the potential and limits of temporal metadata as a type of external memory cue. I aim to explore how a time-based retrospective remembering process might be enabled and supported by leveraging temporal metadata as the key design material shaping interactions and experiences with digital photos. I want to inquire into how different kinds of temporal contextual cues may help situate and interweave digital photos across one's personal history. Thus, my research includes design and field studies detailing how rematerializing and reorganizing digital photos through a temporal lens shapes people's situated experiences of reconstructing autobiographical memories.

2.3. Personal informatics in data-driven lives

The HCI community has had an ongoing interest in how personal data can be represented to support reflection on personal everyday experiences [36,56,82,170,189] and life histories [25,35,55,98] in ways that are open to ongoing interpretation [195]. Prior work has focused on the design of technologies that extend data, such as images or audio recordings, to physical cherished objects (e.g., [67,151,171,175]). Researchers have also begun to explore opportunities for enabling people to re-experience digital media from their past with photos, music, and social media (e.g., [98,113,167,218,219]). Over the past several years, HCI and design researchers have articulated new opportunities for using metadata "as a resource for people to manipulate and personalize their virtual possessions" [170:991]. Through the Curatorial Agents project, Gulotta et al. proposed that temporal metadata in particular 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." [82:3460] 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. Elsden et al. argue there is a need to investigate the design of interactions with personal data that expand beyond "an exclusive interest in performance, efficiency, and rational [self] analysis" [57:48] and that emphasize interactions with personal data "representations that support multiple perspectives rather than reductive explanations" [57:47]. Elsden and colleagues later extend this work to articulate the design approach Documentary Informatics [54] where they propose key opportunities for future research: (i) exploring the role that data could play in shifting orientations to photography as a technology of memory [235] and (ii) giving data a fixed form to enable it to settle in place [216] as an ongoing part of everyday rituals and practices.

Leveraging different kinds of metadata as filters to supporting alternative ways of data *wayfaring* [189] has also been proposed as a key opportunity area for generating new ways of reflectively orienting to key events, threads of history, and lifelong practices bound up in large archives of personal data [57]. Nascent design research has begun to show the promise of creating new technologies capable of supporting more nuanced and alternative interpretations of personal data in ways that can grow and change over time. The Olo Radio project [158,169] explored how metadata could be a resource used to reorganize and re-surface music that had been previously listened to in one's past through different forms of time. This work opened new ideas about how metadata could be a design material for supporting memory-oriented interactions with digital media from one's past in open-ended ways. The design and study of Slide2Remember unpacked how a wall-mounted photo viewer could randomly shows a user's photo paired with a song that was listened around the same time when the photo was taken [114] (see Figure 5). This project demonstrated how pairing two forms of personal digital media that were bound to a similar point in time can support situated experiences of reminiscence. In both instances, by emphasizing the *presence*, *coexistence*, and even *sequence of* different digital instances based on their creation date, these design cases showed how to use temporal metadata as a strong resource to reorganize, resurface, and reconnect people with their personal life history more meaningfully. Yet, to date very limited research on metadata exists in the context of digital photos.

Figure 5: ***Slide2Remember*** **installed on the wall of the home, showing the user's photo and playing music that the user heard in the same period during which the photo was taken**
Images retrieved from Kim et al.'s paper in 2022 [114]

My dissertation seeks to directly build on this prior research and contribute studies that investigate how temporal metadata instantiates a 'place' to have open-ended experiences with vast personal digital photo archives. I discuss opportunities for memory-oriented photo archive interactions and 'wayfaring' through a temporal lens, and the roles that alternative representations of personal data could play in opening a space for exploring one's life history from different perspectives over time.

2.4. Temporality and slow technology

Bound up in a personal digital photo archive, the scale and depth of different points in one's life history are what motivated us to explore how digital photos could be re-experienced through a diverse temporal lens. In their foundational research on *slow technology*, Hallnäs and Redström proposed "a design agenda for technology aimed at reflection and moments of mental rest rather than efficiency in performance" [85:201]. This vision was extended through the critical argument 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" [85:203] and "…that will last and develop over time" [136:11]. Since these foundational works, there has been a growing interest in exploring slowness and temporality as frames for the design of new technologies. Galani and Clarke [70] applied a slow technology framework to catalyze imaginative experiences through an augmented reality museum installation. Grosse-Hering et al.'s JuicyMo [80] and Pschetz and Banks' Long Living Chair [180] each mobilized slowness to give rise to meaningful reflections on embodied practices with each artifact respectively, and prompt reflection their one's relation to them over their lifetime. Taking

an analytical approach, Huang and Stolterman [101] utilized visual representation to examine temporal patterns and usage.

Figure 6: ***Long Living Chair*** **is a rocking chair with enhanced memory, which knows the day it was produced and can record how many times is used over the course of 96 years.**
Images retrieved from Pschetz and Banks' paper in 2013 [180]

A handful of works have explored how slowness could support meaningful experiences with digital data. Examples including the Reflexive Printer [223], Photobox [162], Olly [167], and Postulator [87] provide evidence that slowness can be a resource for supporting rich experiences, such as anticipation and reflection.

Figure 7: ***Reflexive Printer*** **prints a halftone photo from its user's smartphone on thermal paper, and deletes it;** ***Postulator*** **is an online application that allows users to send multimedia messages, including images or videos, to a future date and time.**
Images retrieved from Tsai et al.'s paper in 2014 [223] and Hawkins et al.'s paper in 2015 [87]

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 high level aspirations of slow technology through design in ways that offer people some control over the system, while not compromising the

richness of this approach [163,169,179,181,222]. Pschetz and colleagues [20,181] offer a salient argument that projects aimed at designing for slowness may result in an oversimplification of the dichotomy between fast and slow by treating 'time' as solely a matter of pacing. Extending this argument, Rapp [184] 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.

My dissertation aims to contribute to these strands of research on slowness and temporality. I want to explore how multiple expressions of time can be used as frames to engage people and design temporally diverse interactions with vast digital photo archives.

2.5. Research through design

Because I have an open-ended overarching research question that aims to investigate in-depth human experience of living with digital photos over time, I adopted *research through design* [46] as the primary methodology. It produces real-world design cases that allows me to communicate complicated and abstract temporal notions with other people through a demonstratable artifact [9,19,72,248]. The artifacts also enable people's actual interaction experiences with the systems as evidence for what insights interaction designers and researchers should take into consideration in the future.

Research through design method directs interaction design researchers to investigate the benefits and consequences of potential socio-technical futures through a real-world artifact [248]. Through the production of a design artifact, this approach creates the context for a collaborative interdisciplinary research environment that could involve (but is not limited to) designers, engineers, anthropologists, and computer scientists.

To investigate my research questions, I draw on three specific approaches in and across my cumulative Ph.D. thesis: a *designer-researcher approach*, a *research product approach*, and an *artifact analysis approach*. A designer-researcher approach is a practice-based design research approach in which researchers often work as a

multidisciplinary team to create a research through design artifact and generate insights from a first-person perspective. A research product approach aims to conduct a field deployment study to inquire people's lived experience with a highly finished design artifact that can works independently in field over a long period. Artifact analysis is a reflexive analysis of a collection of design artifacts with an aim to discover new theoretical understandings. In the following subsections, I will unpack the details of each approach.

2.5.1. A designer-researcher approach

I take a *designer-researcher approach* to the creation of artifacts in my RtD process. **This approach gives prominence to first-hand insights emerging through the creation of real things that materially ground conceptual ideas through their actual existence** — "*a process of moving from the particular, general and universal to the ultimate particular – the specific design*" [147:33]. I aim to create new technologies that embody alternative temporal expressions of personal digital possessions and ground discussion around the highly finished design artifacts. The particular designer-researcher approach I take originates with and is tied to design-led research in HCI. In this area, design researchers often function as a small but multi-disciplinary team that is reflexively focused on the experimental and novel outcomes of the design process that are critically and reflectively arrived at through design practice. Thus, design research in HCI can contribute a highly insightful, first-hand, and reflexive view of practices of making design artifacts in relation to higher-level concepts framing key decisions in the design process and in light of attendant materials, tools, methods, and competencies.

Methodologically, this type of research work builds on a trajectory of research in HCI that emphasize the creation of new knowledge through design practice and a reflexive process (e.g., [9,42,58,212,248]). Similar to Schön's notion of design as *a conversation with materials* [199], researchers engage in a reflexive dialogue with theoretical and design materials, and iterative development and critique of design concepts, to arrive at the final artifact design. This practice-based approach explores possible futures with people's real-life experiences and to surface alternative perspectives and experiences. The designer-researcher approach tends to initiate an idea that emerged from personal expertise and research trajectories, pursue both the

robustness and creativity reflexively through crafting and living with the design artifacts, and require to form a unified narrative voice to report our research outcomes [155].

2.5.2. A research product approach

Once a new technology is designed and created, I take a *research product* approach [168] to inquire people's longer-term experience using and living with it in a real-world setting. **Research products are design artifacts that are created to drive a research inquiry in a real-world context and that have a high quality of finish such that people engage with them over time as is (i.e., a thing), rather than what they might become (i.e., a prototype).** Research products are created to operate independently for substantial time periods to support long-term field studies [210] in people's daily environments. For example, they have been rigorously tested in domestic contexts for a number of months (e.g., [74,86,125,162]). In this research product approach, I apply methods such as *semi-structural interview* [202] and *coding* [194] to the deployment for data collection and analysis purpose.

The RtD process does not necessarily need field deployment studies. Knowledge production can be done through the creation of artifacts and embodiment of theoretical concepts. However, with deployment studies, interesting and unexpected insights may emerge because participants reflect on and reframe their own experience from different perspectives. Most importantly, the researchers' arguments can be further solidified by the results of real-world deployment.

2.5.3. An artifact analysis approach

As an additional part of my RtD process, my research team conducted a *review and analysis of artifacts* that are on the same temporally-oriented research trajectory to explore insights for developing a theory of slow technology design. **We reviewed and conducted a reflexive analysis of a series of slow technology design artifacts with an aim to discover new theoretical understandings as an extension of the original proposal of slow technology.** By selecting design artifacts from our own RtD projects, we can offer first-hand insights in and across the artifact collection. This approach reviews the prior design practices and artifacts in a reflexive and integral way. Not only does it inherit the benefits of taking a RtD designer-researcher approach, but that the

artifact analysis approach enables me and our design research team to reflect on the emerging design qualities and tensions in the design space of slow technologies.

Collectively, the three specific approaches in my RtD inquiry were carefully selected to cover my investigation on the particular set of research questions in this dissertation. They each plays an important role in answering the specific sub research questions I stated in the Introduction section. The consecutive research questions and their following approaches I take accumulate and form the entire research process.

2.6. Summary

Overall, this literature review section describes a need to design digital technologies that better support people's memory-oriented photo viewing experience and make the case that interaction design research ought to be more explicitly framed and investigated through a temporal lens. Although slow technology has provided a strategy to facilitate the development, the original paper and its following works did not propose the specifics of how more diverse expressions of time could be considered and created. Thus, I take RtD as the primary methodology and three specific research approaches as support to provide answers along the way.

Chapter 3.

Chronoscope: Designing Temporally Diverse Interactions with Personal Digital Photo Collections

3.1. Overview

As noted in the Introduction, I started my RtD inquiry by closely reviewing numerous prior works in relation to digital photo viewing experiences and personal data. Projects such as Pensieve [174], Olly [166], and Olo Radio [158] show that temporal metadata could be a generative design material for reorganizing one's digital archives and enabling new reflective experiences. At the time, temporal metadata had not been widely explored as a design material within the digital photo research space. This motivated me to have my first research project ground it in design practice and create a design exemplar through a critical and in-depth design research process. Thus, I proposed the following research question for my initial dissertation research:

RQ1: What opportunities exist to leverage 'temporal metadata' as a design resource that supports memory-oriented ways of experiencing the trajectory of digital photos one has accumulated in their life?

To address this research question, my objective was to conduct a practice-based design research study to explore alternative ways of using temporal metadata as a design material that enables people to view their digital photo archives as a whole[1]. My design research inquiry eventually led to the creation of a tangible photo viewer named *Chronoscope*, a domestic technology that leverages temporal metadata embedded in digital photos as a resource to encourage more temporally diverse, rich, and open-ended experiences when re-visiting one's personal digital photo archive. Next, I unpack the details of this design study.

[1] This chapter is adapted from a publication in ACM DIS'19 conference: Amy Yo Sue Chen, William Odom, Ce Zhong, Henry Lin, and Tal Amram. 2019. Chronoscope: Designing Temporally Diverse Interactions with Personal Digital Photo Collections. In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19), ACM, New York, NY, USA, 799–812. DOI:https://doi.org/10.1145/3322276.3322301

Figure 8: **Leveraging the metadata of each digital photo, Chronoscope is a tangible device that enables interactions *through* and *across* time in one's personal photo archive.**

3.2. Introduction

Since the 19th century, photographs have operated as a key resource to support people's practices of self-reflection, identity construction, and contemplation of the future [38]. Today, people's photographic practices are highly mediated by digital devices and services. These technologies have enabled people to create photo archives at scales larger than ever before. As an example, it is estimated that people took roughly 1.2 trillion digital photos in 2017 alone [26].

These massive and still growing archives pose new challenges for the design and HCI communities. As the digital photo archives grow larger, they become increasingly invisible, lacking the material presence that might attract people to notice and engage with the archive in the course of their everyday lives. This issue can also make it difficult for people to grasp just how big their digital photo archives are and what is contained within them (e.g., [245]). Numerous works in HCI have articulated the need for more diverse approaches to designing interactive systems that enable people to experience, explore, re-visit, and live with their digital photo archives over time in everyday life (e.g., [51,160,222,223,229,230]). Despite the wide range of personal experiences and histories captured in personal digital photo archives, few works have explored how more temporally diverse interactions might be supported (e.g., linear and non-linear conceptualization of time).

Interestingly, as a byproduct of people's interactions with digital photo devices and storage systems, a standardized, accessible form of timestamp metadata is generated that captures precisely when a photo was originally taken. Yet, the productive application of metadata like this has largely been overlooked and under-explored as a design resource to support experiences of meaning-making, reminiscence, and reflection [57,170]. In parallel, as interactive technologies and personal data increasingly become embedded in people's everyday lives, researchers have argued that this requires us 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*" [136:11]. How might meaningful experiences with personal digital photo archives be supported and sustained as they grow, expand, and age over time? What opportunities exist for metadata to be leveraged as a design resource that supports new ways of experiencing the trajectory of digital photos one has accumulated in their life?

To explore these questions and ground our own thinking in this emerging space, we designed *Chronoscope*, a robust design artifact that leverages the timestamp metadata attributed to each photo to open up new ways of experiencing the lifetime of digital photos in personal archives with added temporal diversity (see Figure 8).

Figure 9: The Chronoscope UI visualizes the central photo's location in time and provides corresponding data around it.

Chronoscope enables users to interact with their photo archive through three rotational controls on viewing directions, timeframe modes, and viewing granularity. When peering into Chronoscope, a single photo tied to the specific time that it was taken (based on its timestamp metadata) will be visible (see Figure 9). A rotating wheel, as the scope's main feature, controls two directions: navigating forward and backward in time within the selected timeframe mode (see Figure 10). Navigating in a timeframe mode

occurs through a rotational movement (clockwise to move forward in time and counterclockwise to move backward). We selected physical rotation for this input as a subtle analogy to the circular shape of clocks and the temporal flow evoked by their movement. By rotating either direction, the user sees each photo in relation to a wide spectrum of other photos in the archive. When the user stops the rotation, Chronoscope settles on the specific photo associated with where 'in time' the position is in relation to selected timeframe mode. When switching the bigger knob on the side of the scope, users can seamlessly toggle between different temporal organizations of their archive through three timeframe modes (linear, date, time). When a new mode is selected, the center photo in view does not change, while the surrounding photos are replaced with ones from the new timeframe (see Figure 10).

Figure 10: A use scenario of Chronoscope
Left: Using his right hand the user manipulates a fully rotational black silicon surface (rotating clockwise moves 'forward' in time and rotating counter-clockwise goes deeper into the past). ***Middle:*** Peering into the eye piece through a magnification lens, the user views photos from his past. ***Right:*** The user manipulates a black metal knob that 'tunes' the granularity of photos that moved through in each rotation; the untouched knob toggles between timeframe modes.

Chronoscope's design enables the user to explore a wide range of potentially known, forgotten, or entirely unknown connections from different points in the past that are captured in the vast personal photo archives. While Chronoscope's design is highly resolved, the user experience is largely undetermined and unstructured. It does not suggest where one ought to look in their past when deciding to engage with it. In this way, its interaction design is relatively minimal and constrained, while it may give rise to various open-ended experiences—moments of curiosity, contemplation, and exploration. Yet, engaging in the design of this device did produce challenges, particularly in terms of balancing the sheer quantity of data captured in a person's personal digital photo archive with our goal of supporting open-ended and temporally diverse interactions through and across time. Such issues and experiences we encountered through our design process

provoked us to critically consider how designers interested in making technologies that manifest data in temporally diverse forms that can support open-ended (versus goal-directed) experiences over time could be better supported in the future. It is these insights that emerged through the design of Chronoscope that we reflect on in this paper.

3.3. Background and related work

The related work falls into four sections: photo viewing systems, metadata, temporality, and design-led research.

Digital photo viewing systems

Digital photographs have existed for decades and are one of the most pervasive and extensive forms of digital possessions. Numerous researchers in HCI and DIS have describe the important roles digital photos play in supporting people's ongoing processes of exploring and constructing a sense of identity [40,41,89], supporting self-growth [39,131] and shaping people's transitions and development of a cohesive life story [92,93,197,198].

More generally, there has been an ongoing interest in how people's everyday interactions and processes with digital photo capture, storage, and re-visitation could be better supported [22,144]. Building on earlier research on *PhotoWork* [115], the recent work of Broekhuijsen et al. [22] shows new trends in people's stages of photo interactions (*accumulating, curating, retrieving, and appropriating*) –emerging compared to what *PhotoWork* presented in 2006.

Often building on the foundational research noted above, various design research projects related to digital photos have emerged to explore and better support a growing diversity of needs, experiences, and life stages [8,81,160,222,223]. Interestingly, there is growing emphasis placed on the design and exploration of how tangible interactions and experiences can be designed with vast and growing personal digital photo archives (e.g., [8,160,246]). Recently, Hermans et al.'s work has shown the value of designing augmented jewelry that connects young girls' digital photos, showing its precious physical presence of digital possessions [91]. Their work revealed that the attention to form, materials, and interaction triggered people to carefully protect the

design artifact and led to increased perceived value in the overall digital photo archive itself. Another major area of focus in the HCI community has been in how tangible interactions with digital photo archives can open up new ways to organize and share collective memories mediated by digital photos [109,230], provoke social conversations [87,95], and support collective experiences of reminiscence and reflection [87,109,160,174,222,223,228,229,246].

Overall, these collective works indicate that, while limited, there is a nascent but growing interest in exploring new and novel ways to engage people's digital photo viewing experience. Our research aims to extend these works by proposing and reflecting on a novel system that supports rich, open-ended interactions with *personal* photo archives through and across time.

Exploring metadata as a design material

Our approach to designing rich interactions with personal photo archives heavily draws on temporal metadata as a design material. Over the past several years, a growing amount of research projects have investigated how personal data can be represented in new ways to support reflection on people's everyday experiences [56,82,170]. Through the Curatorial Agents project, Gulotta et al. [82] 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.*"

Through a synthesis of five previous studies, Odom et al. [170], propose *placelessness*, *spacelessness*, and *formlessness* as three core experiential qualities of virtual possessions. Perhaps most importantly for our work, they articulated numerous design opportunities for using metadata "*as a resource for people to manipulate and personalize their virtual possessions*." This research helped open opportunities for seeing metadata in a new way for design – not simply as a byproduct of the creation and use of personal virtual possessions, but as a potential design material for supporting new ways of viewing experiences from one's past from different perspectives. Odom & Duel offer an early design research study aiming to mobilize this implication through their creation of OLO radio [158]. This project explored how metadata could be a resource used to reorganize and re-surface music that had been previously listened to in one's past. This work opened new ideas about how metadata could be a design material for

supporting interactions with digital media from one's past in open-ended ways. Yet, no research to date has explored this concept specifically in the context of digital photos.

Our work seeks to directly build on this prior research and contribute a reflexive design-led case investigating how metadata can operate as a rich design material for supporting open-ended experiences with vast personal digital photo archives. In this, we surface and reflect on key differences in applying metadata to photo in comparison to other types of media in this emerging design space.

Temporality and interaction design research

Our research is also influenced by prior works investigating designing for temporality and slowness. Hallnas and Redstrom describe *slow technology* as "*a design agenda for technology aimed at reflection and moments of mental rest rather than efficiency in performance*" [85]. Numerous works have sought to mobilize a slowness framing to investigate how technology can better support experiences of reminiscence, anticipation and even solitude (e.g., [32,87,162,222,223]). These works make clear that the slow technology design philosophy helped give form to a design space that brought the need to consider time and more temporally diverse ways through interaction design research.

Extending this work, Vallgarda frames slow technology as aiming to "*slow down the expressions of computations enough to let us experience them.*" This statement is foundational to her argument that interaction design practice ought to be considered through a set of relations among physical form, interaction gestalt, and temporal form [231]. In parallel, Pschetz [179] makes a compelling argument that it is essential for interaction design research to inquire into generating new possibilities for people to perceive and consider multiple temporalities. The temporal properties of physical materials such as decay and patination are also explored through the study within HCI field [224]. Albeit from a different perspective, this argument resonates with Huang and Stolterman's work [101]. Through several design-oriented inquiries, they developed an analytical way to explore and examine how interaction unfolds over time. They articulate processual categories, including relationships between specific moments, sequences, motion patterns and action paths, and make the case that interaction design research ought to be more explicitly framed and investigated through a temporal lens.

Our work aims to build on this trajectory of research. We want to explore how linear and non-linear expressions of time can be used as a frame to design temporally diverse interactions with personal digital photo archives through a design artifact that enables these experiences.

Design-led research in HCI

There has been increasing interest in the development of new knowledge through the construction of design artifacts in the HCI community. Fallman [58] argues the core activity of design research is giving form to previously nonexistent artifacts to uncover new knowledge that could not be arrived at otherwise. Researchers such as Gaver et al. [72], Sengers et al. [207], Zimmerman et al. [248], Bardzell et al. [9], and Stolterman and Wiberg [212] have articulated design-oriented approaches that are united in their emphasis on the act of making as a means to critically investigate emerging issues in HCI research. Most recently, there is a growing call for HCI research that closely attends to the processes of creating design artifacts [60,64,110,177]. Collectively, these works highlight the need for more examples of design research to develop a foundation from which future methods and theories can be developed.

Our work modestly attempts to bring these different strands of research together. We want to investigate how technologies might be designed to embody alternative expressions of personal data that can support and sustain rich temporal experiences. We do this by grounding discussion around the design of a highly finished design artifact that aims to make concrete new ideas for using metadata as a design material to support temporally diverse interactions with personal digital photos archives.

3.4. Chronoscope design research process

Our approach to our research inquiry originates with and is tied to design-led research in HCI. We adopt a designer-researcher position that gives prominence to first-hand insights emerging through the creation of real things that materially ground conceptual ideas through their actual existence—"*a process of moving from the particular, general and universal to the ultimate particular – the specific design*" [147:33] Designer-researchers often function as a small but multi-disciplinary team that is reflexively focused on the experimental and novel outcomes of the design process that are critically and reflectively arrived at through design practice. Thus, design research in

HCI can contribute a highly insightful, first- hand, and reflexive view of practices of making design artifacts in relation to higher-level concepts framing key decisions in the design process and in light of attendant materials, tools, methods, and competencies.

As an interaction design research team, we created Chronoscope in our design studio setting to explore potential future temporally diverse interactions with personal digital photo archives. The studio environment and culture supported us to iteratively and simultaneously experiment with digital prototypes and physical forms. This process enabled us to reflectively examine the interplay among interaction, temporal expression, physical form, and materials, and their individual and collective relation to our conceptual framing. Our design team includes two primary investigators and other researcher with expertise in computer science, electronics prototyping, form design, and digital fabrication. We want to create a design artifact that could open a broader space for navigating one's photo archive through linear and non-linear temporal organizations. The goal of our inquiry is to better understand how designing temporally diverse interactions might catalyze a range of open-ended experiences, such as curious exploration, interpretation, and reflection on memorable, forgotten or previously unknown connections in and across the experience captured in a personal digital photo archive. Our interest in this notably wider spectrum of potential interactions is in part inspired by the concept of *ecphoria* [225,226] which refers to the experience of recalling a fuzzy or entirely forgotten memory when prompted by sensory input – in our case, digital photos from one's past.

Our design attitude was influenced by several approaches including ludic design [73,74], reflective design [207], and slow technology [85]. Methodologically, our work builds on a trajectory of research in DIS and HCI that emphasize the creation of new knowledge through design practice and a reflexive designer-researcher approach (e.g., [9,42,58,212,248]). With this in mind, the development of Chronoscope consisted of the following. We reviewed theoretical literature, studies, and a range of design works. Similar to Schön's notion of design as a conversation with materials [199], we engaged in a reflexive dialogue with theoretical and design materials, and iterative development and critique of design concepts, to arrive at the Chronoscope design.

Working with metadata to explore alternatives for organizing and engaging with digital photos

While we explored design ideas related to interaction, form, and materials in parallel, an important early decision was to develop working software that could capture, structure, and organize a user's digital photos based on the metadata records encoded into each photo related to exactly when, where, and at what time the photo was taken. We decided to initially focus on Dropbox as the platform to link users' personal digital photo archives for a few important reasons. First, the service is robust, preserves the integrity of photo metadata, and offers an API that makes the photo archives efficiently accessible. Second, it can be configured to automatically sync with one's digital photo archive as long as the Chronoscope app is authorized, making it easy to maintain an up-to-date archive. Third, the service has been around for over a decade, which makes it possible for us to engage with large and still growing photo archives.

This decision does come with tradeoffs: a key limitation is that not 'all' digital photos that a user has taken in her life are necessarily guaranteed to be captured in these archives. Yet, it did offer stable, substantive, and continually growing networked digital photo archives contained within a widely adopted service that hints at what likely will become one major kind of large personal photo archives that people increasingly accrue over time.

We then developed a Python script that generates a unique, daily updated database of a user's entire personal digital photo archive complete with metadata elements associated with each photo. In this way, Chronoscope sits outside of the direct infrastructure of a user's pre-existing personal photo archive; it mirrors but does not directly influence it. This decision supported our aim to not 'replace' people's current experiences with their digital photos, but rather to leverage these pre-existing practices and *extend* them.

Taking into account our aim to design a personal photo viewer, we iteratively developed a technique to generate thumbnail size images that would be easily portable to a smaller, embedded display. This also enabled us to work with vast amounts of digital photos in a fast and more flexible way. We then tested our software with various design team members' personal Dropbox archives that exhibited, at that time, a range between 35,000-160,000 photos. Through this process, it became clear that we needed

to develop an approach to balancing the richness of each individual digital photo and the sheer scale of content, while keeping the design relatively simple and engaging.

Temporal and geolocative metadata presented intriguing materials for us to leverage in grappling with this complex design issue. Through early experiments using each type of metadata available from digital image files (see Table 1), we found that temporal metadata, as our primary design material, emerged as the best fit to our goals of creating a technology that supported exploration of prior life experiences across and through time. This triggered our next move, which was to explore how we could structure a large personal photo archive in temporally evocative ways. A linear temporal sequence (e.g., similar to a timeline) emerged as an initial metaphor that could easily be mapped to direct manipulation. Considering the sheer size of such archives, a rotational interaction for manipulating and navigating digital photos appeared intuitive – rotating clockwise implicitly suggested moving 'forward' in time (closer to the most recently taken photo), while rotating counter-clockwise moved 'back' in time. A continuous rotational interaction also appealed to us because it was extensible; as one's photo archive grew, it only required more rotations to navigate it. Conceptually this meant we could support a boundlessly growing archive without a mechanical 'endpoint' blocking navigation once a terminal size of the photo archive had been reached. (although *practically* this created other design issues that we had to overcome as described later).

Table 1: Partial EXIF data that could be used as design materials

Camera		**Time**	
Make	Google	**DateTimeOriginal ***	2019:03:31 13:51:24
Model	Pixel 3	**CreateDate**	2019:03:31 13:51:24
Exposure	1/2347	**ModifyDate**	2019:03:31 13:51:24
Aperture	1.8	**Image**	
Focal Length	4.4 mm	**ImageWidth**	4032
ISO Speed	57	**ImageHeight**	3024
Flash	Off	**Compression**	JPEG (old-style)
Location			
Latitude *	49.210597 N	**Altitude**	22.06 m Above Sea Level
Longitude *	123.008689 W		

* prone to support people's contextualization of memories

Yet, using temporal metadata to only represent one's vast digital photo archive in a linear order seemed underwhelming and unlikely to support the diverse range of exploratory, unexpected, and reflective experiences over time. This prompted us to explore how we could use the metadata of each digital photo as a resource to generate various ways of temporally and thematically organizing all elements in the archive. We then conducted iterative design investigations that involved creating scripts to explore different kinds of metadata organizations and structures. Prototyping an application in Processing that initially used rotational movement via a rotational button on a Nintendo switch greatly aided us in this process by offering a visual representation of the specific photo that was the central focus of the experience, while also making visible other forms of secondary metadata that was associated with the image (e.g., geolocative data, file size, device the photograph was originally taken on). While somewhat crude, this design move helped us overcome the feeling of being overwhelmed by the sheer amount of photos and attendant types of metadata in a large photo archive.

Somewhat incidentally, our early visual prototype enabled us to quickly move across a large number of photos in an archive while simultaneously seeing timestamp information separated by *time of day* and *date* (see Figure 11). This opened up two important kinds of experiences. First, we were able to deeply focus on one photo and put the textual representation of metadata beside it to jog the user's memory of details surrounding the experience in it. Second, if the meaning of the photo was unclear or curious, we could rapidly navigate through clusters of photos before and after it to stimulate recollection of past experiences peripheral to it. Through this process, we found that temporal metadata offered an accessible and vibrant range of ways for a user to explore possible recognizable and lesser known patterns and connections in, around, and across their vast photo archive. We then iteratively developed three distinct timeframe modes for organizing a user's digital photo archive that ultimately seemed to make use of temporal metadata to open up a diverse set of possibilities while still balancing the need for the user experience to remain intelligible.

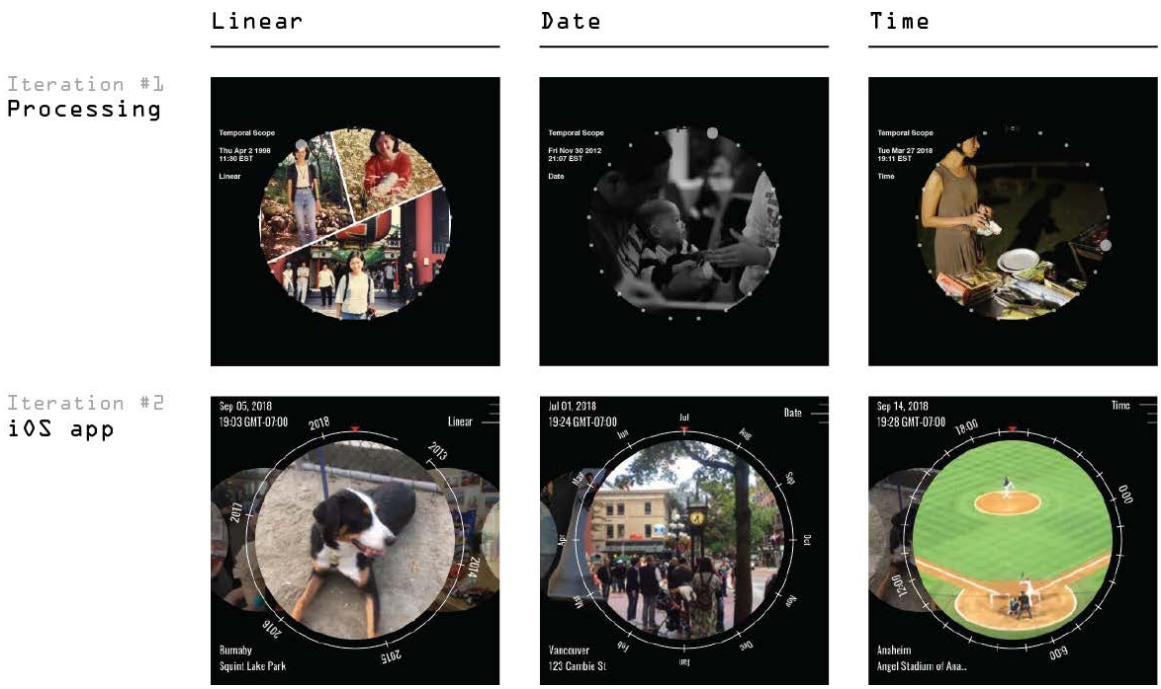

Figure 11: The evolution of the Chronoscope user interface.
During the first iteration with the Processing app, we listed the metadata text of *time of day* and *date* into two different rows (see upper left) that incidentally revealed intriguing ways to apply and structure metadata in our second iteration (bottom left). The final design shown in Figure 9 is modelled after iteration 2.

The three modes are *linear*, *date*, and *time*. *Linear* organizes in a linear timeline, from oldest to most recently taken. *Date* structures all photos in a temporal ordering based on the Month and Day they were taken irrespective of the year, potentially offering a more 'seasonal' way of exploring photos in one's archive. *Time* organizes all photos based on the specific time of the day they were taken irrespective of date or year, opening a space to explore the rhythms and qualities of past experiences captured in photos bound to parts of our 24-hour cycle. One interaction example can be seen in Figure 12.

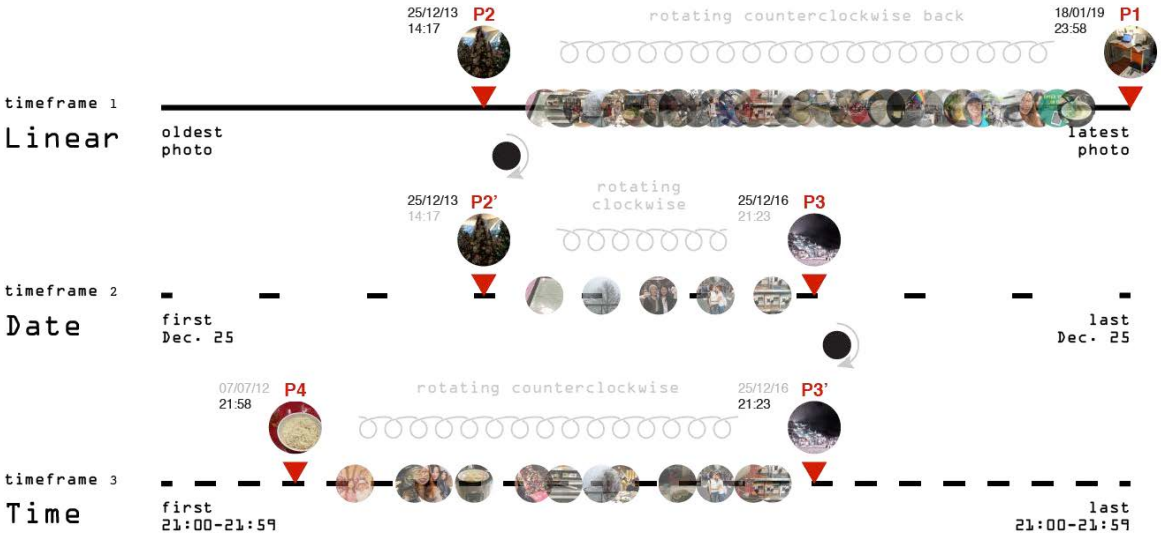

Figure 12: Scenario of moving across the three timeframe modes.
Imagine a user turns on Chronoscope and begins at P1 (on the top right) in the *Linear* timeframe. She rotates counterclockwise back in time to P2, and shifts to *Date* mode, where she can see the surrounding photos are replaced with other photos upon her arrival at P2'. From P2' to P3, she observes a series of photos capturing experiences on Christmas in the past few years. After she switches to *Time* mode at P3', there are a bunch of photos taken at 21:00-21:59 for her to explore.

A cornerstone decision in the interaction design of Chronoscope consists of the following. When the user changes the timeframe mode, the specific photo that is currently viewable does not change; rather, the organization of all of the photos around it changes in relation to its specific timestamp metadata. This enables the viewable image to act as an 'anchor point' through time and, in effect, empowers the user to explore a wide range of temporal connections between different photographs taken at different points in his or her past. Our design team judged this to be an important and valuable design decision because it creates a space of possibilities for people to experience known or perhaps familiar connections among different photos, as well as to encounter and explore forgotten or previously unknown connections. Thus, this decision helps support our goal of triggering a potential range of experiences through interactions with Chronoscope, such as interpretation, reflection, curiosity and serendipity over time.

Manifesting temporal interactions across the archive

The next stage of our design process required us to develop a robust working prototype and grapple with user interface design decisions on a smaller, more personal and intimate photo viewer display.

Overall, we have created two prototypes. One is a Processing app (as mentioned in the previous section) we produced early in our design process to rapidly explore interaction and interface design alternatives. The other one is an iOS app that enabled us to quickly generate up-to-date photo archives locally. We applied the same logic from the Processing prototype and translated the programming codes into Objective-C to create a working application on the iOS platform. This shift enabled us to fluidly create, test, and prototype interactions with actual large photo archives (e.g., 160,000 distinct images). We then redesigned the user interface (as shown in Figure 11) and distributed the mobile app for testing among our design studio and members of our studio outside of the design team. This early app version of Chronoscope enabled us to sync it to our own digital photo collections (assuming they stored their photos in Dropbox). Through a reflexive process of living with the prototype application, discussing our experiences with it among the design team, and interviewing others members in our studio that were using it as well, four insights surfaced and broadly impacted our final design: *timeline style*, *time index of current center photo*, *timeline labels*, and *visual arrangement of metadata*.

As Figure 11 shows, all the information in the Processing prototype is presented on the top left, which requires time to digest the heavy text and makes it hard to notice the three timeframe modes. No clear indication of location in time is noticeable. Therefore, we made several adjustments in the iOS version. The first is the timeline design. As the second row in Figure 11 shows, each marked scale stands for one unit of time (e.g., year, day, hour). The red index indicates the user's location in time. It remains at the top of the timeline. When the user is switching photos in a timeframe mode, the circular frame rotates to provide a subtle indicator that the new selected photo is at a different location in time. We also included photos right next to the center photo and have them smaller and more opaque. By doing so, we were able to generate a stronger sense of *peripheral awareness* that could help encourage a sense of curiosity in the user or put together unanticipated idiosyncratic connections *in* and *across* the photos and modes potentially, while leaving it open for them to make their own self-determined decisions.

Furthermore, we included a handful of labels on the scales to make clear to the user which timeframe mode they are currently in. The timeframe mode indicator on the top right part of the screen helps users make sense of the different temporal

organizations of their photo archive. When the mode is changed, there is an animation of the new photo collection sliding and fading in (and the old one sliding and fading out), which we intended to draw attention to the transition between modes. Last, geolocational data in presented on the bottom left of the interface to offer a subtle reminder of where the photo was taken (e.g., in the case that the photo is not immediately recognizable or otherwise completely unknown).

Our experience of using and reflecting on the iOS prototype app of Chronoscope among design team members also revealed new design issues. To begin with, the fluidity—the ability to zoom through the photos—was not supported well due to the interactive constraints of a mobile phone. This generally complicated our ability to experience a sense of flow as we moved in and across our respective photo archives. The typical gestures people used to interact with mobile apps made the interaction with Chronoscope either too discrete (e.g., tapping to advance forward or backward in time) or too imprecise (e.g., swiping to move through a small sequence of photos). Although the iOS prototype validated core aspects of our design, the quick rotational movement through one's massive archive was not well supported compared to the continuous interaction supported by the switch controller in the Processing prototype.

It also became clear that we needed to add in subtle support for more *peripheral awareness* – representations of photos directly next to the one that is currently being viewed in order to support a sense of transition change when entering a new time mode. Through iterative design explorations of the peripheral awareness concept, it became apparent to us that this is an interesting and important temporal interaction feature because it is quite different from typical or traditional interaction design practice – the idea of replacing all the *surrounding* data elements of the entity being viewed to indicate a timeframe mode change, rather than changing the core entity itself. While nuanced, this subtle feature proved to enrich the interactive experience with Chronoscope, which we elaborate on more next.

Balancing scale and tuning temporal granularity

The design insights that reflexively surfaced through our creation and use of the first two prototypes redirected us to explore more engaging photo viewing experience with a tangible prototype that not only adopts the technique of using rotational movement to switch photos and timeframe modes but also supports movement through the sheer

size of one's massive photo archive. To fully realize this vision, we made the design decision to use rotatory wheels to imply the ongoing, fluid notion of time. On a technical level, we achieved this goal by designing an electronic circuit with three rotary switches, 240 x 240 LCD color display and a Raspberry Pi Zero W as Chronoscope's embedded CPU.

However, we encountered a tension related to the sheer size of the photo archive. For example, if a user has 20,000 photos and she aims to navigate to a specific time of her photo collection, it would take her about 2.77 hours to get there since each rotation moves through the photo archive by only one photo as a unit (and it takes about 0.5 second per rotation). With a larger archive, such as 200,000 photos the scenario is much worse (about 27.7 hours of continuous rotation).

This design issue revealed to us that we would need to build in a support for 'tuning' the number of photos (or granularity) that one moved through for each rotation. In other words, we needed to enable people to move through their photo archives in very slow, precise and considered ways if, for example, they encountered a set of photos that triggered deep reflection or examination. Equally, we needed to provide quick movement across vast amounts of photos without an excessive amount of rotations, while retaining a subtle awareness of what had been passed over. We termed this interaction design quality *temporal granularity*. With added control over the number of photos to be moved across in each degree of rotation, people would be able to 'tune' the speed through time that they move across elements in their photo archive. This decision was influenced in part by Gaver and colleagues' concept of balancing *control* and *drift* [73,74]. The 'tuning' feature opens up more freedom and flexibility for the user to move through photos from minutes in a day to years of one's life, making it easy to slow down or speed up in real time. Ultimately, we found this design decision to be valuable in that it makes use of metadata to support not only movement *across* time (both the linear and non-linear modes), but also movement *through* time in a more extended or diverse way.

We iteratively worked to establish upper and lower boundaries of the temporal granularity knob, which proved to be a delicate balance. Through these design explorations, we found that if the upper bound of photos users could move *through* with one rotation was too high, they would easily get '*lost in time*'. Imagine if a user made one rotation and moved 10,000 or 20,000 photos ahead in time. Even with the metadata the

photo visible, experiences like this were quite confusing, disruptive and unpredictable. However, if the maximum threshold was too low, then we would experience getting '*stuck in time*' where, in all likelihood, we would never be able to get out of the general place in time that we were located at unless we toggled between various modes (e.g., if you could only advance 5 photos per rotation and you had 200,000 photos, it would still take forever to arrive the target destination). Ultimately, through this reflexive process of trial and response among our design team, having 1 photo per rotation as a minimal threshold worked well, while having 300 as the upper limited provided an ideal balance.

Creating a form to invite curious exploration over time

Giving an appropriate physical form to Chronoscope pushed us to critically consider the aesthetics, material presence, and holistic integration of design elements. Our process was highly inspired by scope-like forms which not only suggest rotation-based tangible interaction but also invite users to view and contemplate the viewed phenomena in an intentional, inquisitive way (see Figure 13).

(a) Rotation (b) Kaleidoscope [214] (c) Telescope [111]

Figure 13: Form and Interaction Design Inspiration

Throughout the ideation process, we looked toward the aesthetics, functions and the human-object relationship of various types of scopes for inspiration. For example, we considered the role of telescopes in probing and exploring outer space and microscopes in closely observing biological organisms and molecules. We also considered kaleidoscopes that use embedded mirrors to reflect objects and generate repeating geometric patterns, and often work for both direct in-use entertainment and decorative ornaments in one's home. Although exhibiting clear differences, these three scope examples represent quality objects that can be directly engaged and simply lived-with.

Collectively, these scope artifacts enable people to see what they normally cannot in unusual and potentially profound ways. These explorations inspired us to adopt a scope-like form for our final design artifact—one that would encourage deep consideration and exploration of elements in one's personal archive. The near-eye viewer quality of this form is also notably personal and support our goal of design for experiences of individual reflection on one's past. This decision primed us to the next stage of designing the physical form for the Chronoscope.

We arrived at the primary rotation wheel design (see Figure 10-Left) due to its corresponding size as the circular timeline design on our interface. We associated the respective timeframe modes and temporal granularity with a similar style of rotary switches and knobs common on microscopes to adjust the visual focus (see Figure 14).

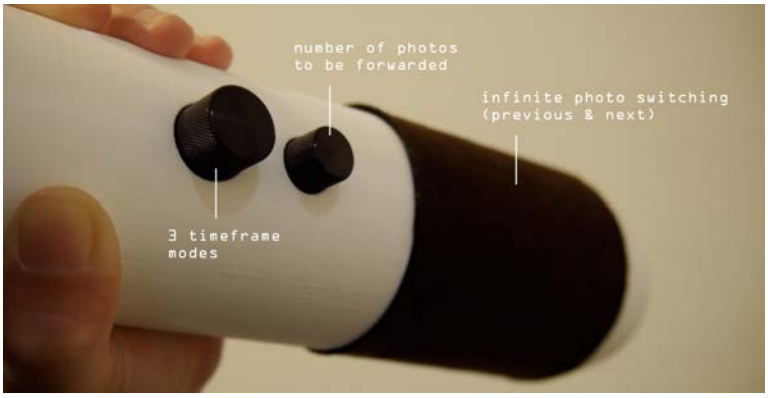

Figure 14: Three physical controls used to select viewable photo, timeframe mode, and to *tune* the temporal granularity.

Regarding materials, the use of silicone and quality fabricated plastics offers durable, cleanable, and long-lasting materials. It also enabled us to easily use color to accentuate parts of the design and make them easier to use while still holding up over time. The physical form itself is of a size easily usable for many people of different ages and sizes; that is, it could be eventually passed down or take on different roles over time (e.g., an elder that once had it when young, uses it to show and tell stories to a grandchild about what life was like before). We envision Chronoscope to have a similar longer-term position and quality of use in people's lives, which oscillates between direct interactions and passive presence as a person's photo collection grows and ages over time.

3.5. Discussion and implications

Developing approaches and strategies to create design artifacts that express different perspectives on and representations of vast personal digital photo archives over time presents important opportunities for the HCI community. Through a critical reflection on our design-led research process, we highlight challenges that come with this emerging space and insights into how they could be better grappled with in future research and practice.

3.5.1. Designing interactions with personal photos *through* and *across* time

Chronoscope's defining quality is its open-ended, and relatively undetermined character, which is projected through its interaction design, physical form, and unobtrusive, yet inviting aesthetics. Core to our aim of supporting opened-end experiences is the use of temporal metadata to offer a range of possibilities to the user – to explore known past memories, stumble into once forgotten, yet easy to recall prior experiences, and to explore and potentially make connections across non-linear temporal trajectories of one's personal photo archive.

Prior research has shown how *randomness*, in particular, has emerged as a popular strategy for catalyzing open-ended experiences with large archives of digital photos [162,223] and more generally digital media [118,119]. Yet, while valuable, such an approach would fail to make use of the precise temporal information that metadata offers as a valuable design resource. Further, simply implementing a random approach might open an opportunity to reflect on a specific past moment in time, but it would miss the opportunity to open up new possibilities for establishing connections among digital photos *through* and *across* time.

The precision offered by the collective amount of temporal metadata spread across individual photo elements in a personal archive enabled us to develop a novel interaction design that offered users total control over navigating and viewing their archive from various perspectives, while leaving the chosen pathway undetermined and up to them. Yet, design process was not a straightforward path. Through working with the metadata, we eventually developed three different timeframe modes for organizing a

photo archive. This offered a technique that could enable a user to explore connections *across* 1 linear ('linear') and 2 non-linear ('date', 'time') conceptualizations of time. We then iteratively developed an approach that supported dynamic, continuous navigation of photos, whether backward or forward, *through time*.

These design moves were key to the early success of our design process. However, we quickly encountered additional design issues. The sheer size of digital photo archives could easily leave users *stuck in time* – it could require days of continuous rotations simply to navigate through all of one's digital photos if one photo or a few advanced per one rotation (indeed it is easy to imagine that it could take weeks or months as we consider the size of digital photo archives in the near future). This prompted us to design an additional interaction feature that could enable users to 'tune' the number of photos that would be advanced per rotation. Yet, this introduced other challenges. If the upper threshold was too high, then a user could easily become *lost in time* as they navigated a large amount of photo in one turn (i.e., effectively flashing ahead into the future or back into the past without a clear point of reference). Ultimately, through an iterative process, we determined that an approximate threshold that would help mitigate these collective design issues – at least for the time being.

Our unpacking of the design process illustrates that there are opportunities for future research to explore how temporal metadata can be used as a resource for supporting idiosyncratic and self-determined explorations of vast personal data archives *across and through time*. Yet, it is also clear that design researchers are likely to encounter design issues related to the scale and temporal dimensions of personal data archives, which may be difficult to anticipate. In our view, there is a need for future research to better understand and develop design techniques, approaches, and strategies that enable such rich and diverse temporal interactions with their vast personal archives. Our work suggests that *tuning temporal granularity* is one pathway into supporting future HCI research and practice initiatives in this emerging territory. There is an opportunity to explore designing interactions *through and across time* further in the context of digital photo archives on both personal and social levels, as well as for other types of data (e.g., audio, video, text, social media data, etc.).

3.5.2. Investigating metadata as a design resource

Building on prior work [158], our design process highlighted a need for new approaches to support practicing designers in understanding and working with metadata as a design resource as a *starting point* in the design process. Our early incidental decision to prototype a visual interface that displayed metadata (primarily including temporal and location data) as we rotationally navigated through a linear organization of photos crucially informed our design approach and, ultimately, our final design. Through iterative explorations, we developed techniques for organizing a user's photo archive in different temporal formats. This proved critical for our design team to gain a better grasp on how to conceptually and practically deal with the sheer size and scale of large personal photo archives. However, as noted, these early experiments were crude and somewhat accidental. While they operated as 'windows' into the possibilities that such metadata might offer, they were very primitive on visual, expressive, and interactional levels. These barriers and the bottom-up approach we had to adopt to develop our own visual applications and technical infrastructure delayed our moves to develop a sensibility for understanding the temporal aesthetics of digital photo metadata and the potential value they might have for design. Ultimately, these efforts were worthwhile as they catalyzed our development of a rich rotation-based interaction design combined with the ability to toggle *across* linear and non-linear timeframe modes and 'tune' one's desired granularity for moving *through* time. Taken together, these elements produced the defining design quality of Chronoscope.

As interaction designers increasingly aim to leverage metadata as a *design material* [82,158,170], there is an opportunity to develop new interactive tools that better support design teams in rapidly surfacing and prototyping different temporal textures, patterns, and themes in large metadata archives. Similar to how our incidental early experiments eventually led to a novel interaction design, such resources could better support the development of richer design strategies and design exemplars that can be scaffolded in the next stages of the design process. Better supporting such creative and frenetic practices early in the design process will help designers develop a deeper sensibility and intuition for working with large personal media archives. We imagine that this, in turn, will help generate opportunities that better respond to calls in the HCI community to create design artifacts that exemplify rich and diverse alternative expressions of personal data in everyday life [54,57]. Research in the DIS and HCI

communities has already begun to develop initiatives to support designers in getting a grasp on the immateriality of software, data, and algorithms [48,172,201] that could be leveraged in support of future research in this direction, as could research on developing tools for designers [141,211].

3.6. Conclusion and future work

Through grounding our design-led research in the proposal of Chronoscope, our work aims to contribute to growing calls in the design and HCI communities to create design artifacts and exemplars capable of a) opening possibilities for forming relations to and interpretations of our growing amounts of personal digital data [57,160,203] and b) expressing more diverse perspectives on temporality through design [126,179,232]. Our proposal and description of the Chronoscope design artifact helps make a concrete approach to making use of temporal metadata as a design resource to express and offer engagement with multiple temporal representations of and interactions with one's digital photo archive. Chronoscope's interaction design paired with relatively minimal feedback (other than photos from one's life) offers promise to open a space for a range of open-ended experiences to emerge with it over time.

Importantly, our aim is not to be conclusive. Rather, we aimed to describe, unpack, and critically reflect on the Chronoscope in a generative way to inspire future design-oriented research that inquiries into the place, pace, and expression of personal or social data in people's everyday environments. In our future work, we aim to create a small batch of highly-finished, robust Chronoscopes to deploy and study in the context of people's everyday lives. We want to further understand how temporal metadata can be applied as a design material to support linear and non-linear encounters with prior life experiences captured in personal digital photo archives. On a broader level, we hope that our detailed reflexive description of Chronoscope and discussion of the resulting implications can be appreciated as an effort to better support design-oriented forms of knowledge production in the HCI community.

Chapter 4.

Crafting temporality in design: Introducing a designer-researcher approach through the creation of Chronoscope

4.1. Overview

Building on the Chronoscope design study in the previous chapter, I reflected on the Chronoscope design research process more deeply from a methodological perspective. It was through this process that my second research question emerged:

RQ2: What are viable conceptual frameworks for conducting practice-based design research that utilize notions of time to invite one's reflection on their vast and still growing digital photos?

For this question, in collaboration with my supervisor, I led the writing of a book chapter in a research handbook for a broader audience of practice-based researchers and practitioners[2]. We critically reflected on what design philosophies and approaches had highly impacted how we think and make design decisions throughout a design-led process. This publication gives a sense of what our research team's particular designer-researcher approach is and position this approach among existing practice-based research methods or concepts in the design research field.

Next, I unpack the details of this particular designer-researcher approach.

[2] This chapter is adapted from a book chapter: Amy Yo Sue Chen and William Odom. 2021. Crafting temporality in design: Introducing a designer-researcher approach through the creation of Chronoscope. In The Routledge International Handbook of Practice-Based Research. Routledge, 368–380.

4.2. Introduction and background

We now live in a world where digital technologies mediate many aspects of people's everyday lives, and this situation challenges design-led research as it struggles to adapt its methods to the speed of rapid technological change. The convergence of social, cloud, and mobile computing have made it easy for people to stay constantly connected, and to create and share personal data at rates faster and scales larger than ever before. For example, social media services currently receive approximately 21,000 photo uploads per second and 657 billion photos annually [140]. These new technologies have enabled people to create vast digital archives that capture their personal history and life experiences, which can be valuable resources for connecting with others and reflecting on one's own life. Technological trends toward constant connectivity and the proliferation of personal data have opened many benefits. However, wide-ranging experiences of overload are emerging as people struggle to make sense of the masses of digital data they now create and receive. People are experiencing loss of control over the digital archives that capture their life experiences as they become oversaturated and fragmented [170,205]. Therefore, there is a clear need to develop new ways to support people in making sense of their ever increasing archives.

Technologies are being designed without a clear sense of how people could develop longer-term experiences with them and the digital media archives that they produce. This threatens the ability for digital media and technology to be enduring valued resources for meaningful activities, such as reminiscence, contemplation, and social connection. These consequences are likely to become even more entangled and complex for future generations if current trends continue. As interaction design researchers, we cannot help but wonder: How can we advance design processes to enable digital artifacts to more appropriately support the meaningful activities of people's lives? How can technology be designed to become longer-term everyday resources that evolve over time? What kinds of interaction qualities and design decisions ought to be taken into account in design practice to engage with these issues?

In their original article on *slow technology*, Hallnäs and Redström advocate creating technology that persists for long time periods in people's lives [85]. At the heart of this design philosophy is the aim to encourage experiences of self-reflection as well as critical reflection on technology itself; and, investigate 'what it means to design a

relationship with a computational thing that will last and develop over time' [136:11]. Slow technology offers promise of addressing digital overload. Yet, its conceptualization is still underdeveloped and exemplars of how it can be translated into viable design strategies are sparse.

Research through Design (RtD) is an emerging interaction design research method that grounds theoretical investigations through the research-creation activity of design practice [e.g., 62,72,186]. The highly polished and robust design artifacts produced through RtD each operate as exemplars of theoretical ideas and conceptual propositions. They also offer concrete ways to reveal new knowledge about how complex social issues, like digital overload and supporting longer-term human-technology relations, can be reframed and approached.

In parallel, recent work in the computing and interaction design communities has highlighted the need to design technologies that express alternative representations of personal data capable of enabling experiences that expand beyond 'an exclusive interest in performance, efficiency, and rational [self] analysis' [57:48]. Yet, examples demonstrating and unpacking how the slow technology design philosophy can be put into practice are rare. Examples demonstrating how such rich and unique engagements with personal data can be supported through the creation of new design artifacts are equally sparse.

To bring together research across these two areas and to ground our own thinking in this space, we designed *Chronoscope* – a tangible photo viewer that embodies the lifetime of digital photos a person has accumulated over their lifetime. Inspired by prior research on designing for slowness [85,162,232], key qualities of *Chronoscope's* design include it: *takes time to understand*; *manifests change through time*; and *leverages different forms of time to prompt reflective experiences by manifesting their presence in everyday life*. As Figure 15 shows, *Chronoscope* is a domestic technology that leverages temporal metadata embedded in digital photos as a resource to encourage more temporally diverse, rich, and open-ended experiences when re-visiting one's personal digital photo archive. Its scope-like form not only suggests rotation-based tangible interaction but also invites its users to view and contemplate the viewed phenomena in an intentional, inquisitive way.

Figure 15: Leveraging the metadata of each digital photo, Chronoscope is a tangible device that enables interactions through and across time in one's personal photo archive. The scope form and the monocular feature are designed to suggest its user a consciously focused viewing experience.

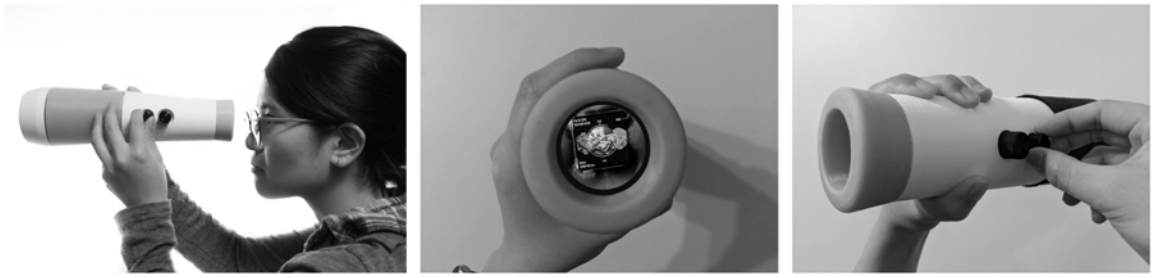

Figure 16: A use scenario of Chronoscope
Left: The user manipulates a fully rotational black silicon surface (rotating clockwise moves 'forward' in time and rotating counter-clockwise goes deeper into the past). Middle: Peering into the turquoise eye piece through a magnified lens, the user views photos from his past. Right: The user manipulates a black metal knob that 'tunes' the granularity of photos that moved through in each rotation; the untouched knob toggles between timeframe modes.

When peering into *Chronoscope*, a single photo tied to the specific timestamp will be visible (see Figure 17). All the photos are reorganized in a chronological timeline. There are three rotational controls to navigate through the photo archive (see Figure 16). The primary rotating wheel controls the *viewing directions* in one timeline (clockwise to move forward and counter-clockwise to move backward). By rotating either direction, the

user sees each photo in relation to a wide spectrum of other photos in the archive. The other two knobs on the side decide the *timeframe modes* and *viewing granularity*. For timeframe modes, users are allowed to switch between three timelines – *linear*, *date* and *time* – each organizes photos based on different part of the timestamp. As for viewing granularity, we use a rotational slider as a build-in support for 'tuning' the number of photos (from 1 to 300) that one could move through by each wheel rotation. More details could be found in our full paper published in DIS'19 [31].

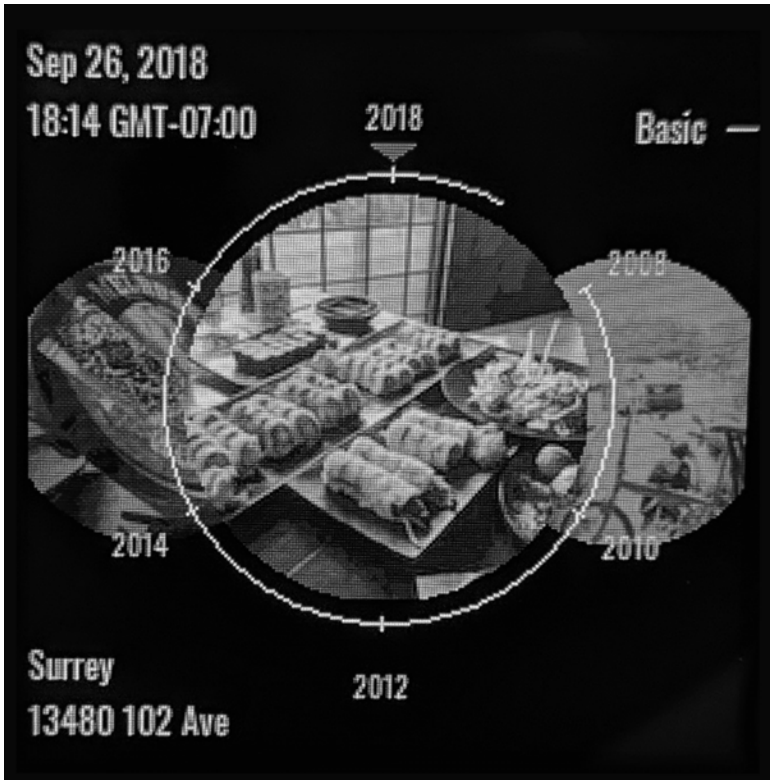

Figure 17: The Chronoscope UI visualizes the central photo's location in time and provides corresponding data around it.

As a slow tech design practice, *Chronoscope* works slowly through offering alternative angles for people to curiously explore and reflect on their digital photo archives through and across time. Through designing in support for the presence of time and adding navigational controls for temporal exploration, several interaction qualities emerged during the design process and field testing of *Chronoscope*. Next, we draw on the design case of *Chronoscope* as a design example to introduce and reflect on our Designer-Research approach to practice-based research.

4.3. The designer-researcher approach

Over the past several years, we have adopted what we call a designer-researcher approach to making and reflecting on highly finished design artifacts as a form of practice-based research in-and-of-itself. *Chronoscope* represents one of our latest projects in this line of work. The Designer-Researcher approach often involves a small but multi-disciplinary team that is reflexively focused on the experimental and novel outcomes of the design process that are critically and reflectively arrived at through design practice. To give a bigger picture, we introduce four main points that inspire and situate the position of our approach: **(1) Research through Design, (2) Autobiographical Design, (3) Reflective Conversation with Materials, and (4) Research Product.**

With these concepts in mind, we attend to key details in the creation of *Chronoscope* by oscillating between higher-level conceptual ideas and practice-based design decisions. In the following sections, we share with you a brief description of each point and how they specifically motivated the direction and development of our design process.

Research through design

We take a research through design (RtD) method that directs interaction design researchers to engage 'wicked problems' through a real-world artifact to understand how the world could change from its current state to a preferred state. Through the production of a design artifact, this approach creates the context for a collaborative interdisciplinary research environment that could involve (but is not limited to) designers, engineers, anthropologists, and computer scientists. Most importantly, there are four lenses to evaluate a RtD approach from the original paper:

- *process* that could be reproduced with rigor and rationale
- *invention* built on concepts that could potentially answer the research questions
- *relevance* of real-world knowledge and a preferred state to achieve via artifacts, and
- *extensibility* that aspires the research insights to be applied in the future.

Due to the qualitative nature of our research questions and the increased complexity in designing digital technologies, we decided to adopt RtD in the *Chronoscope* project. The four lenses were carefully applied throughout the entire process, from our overarching research goal to every nitty-gritty design decision.

First, we make sure our research *process* is reproduceable. The term 'reproduceable' does not necessarily mean to produce the exact same results but to report rigorous details with clear rationale. The gist is to clarify why the process proceeds with certain decision in each step and how it arrives at the final insights. For example, we started the *Chronoscope* idea based on a rotational photo viewing control with an analogy of clock (e.g., clockwise to move forward in time). Therefore, we settled on its scope-like form because it suggests rotation-based tangible interaction and invites people to view their digital photos in an intentional, inquisitive way. With this decision, we moved on to polish its color and texture to ensure that every little design feature meets our research need. By reasoning details, the process can be examined, learned, and applied by other researchers.

Through another lens, *invention*, we conducted extensive literature reviews in relation to digital possessions, personal informatics, photographic practices, and memory studies to situate our subject in an academic standpoint. *Chronoscope* is deeply researched on the characteristics of data that have challenged people's original sense of owning physical objects, such as being intangible and pervasive in its nature. Without proper tools and structures, people have difficulty making sense of, organize and use photos. Thus, we looked into how reflective and curious experience could be supported by exploring alternative ideas such as the 'circulation' concept between personal memories and memory objects. Our design attitude for this exploration was also influenced by theoretical approaches such as ludic design [73,74], reflective design [207], and, especially, slow technology [85]. Building on these collective works, we invented *Chronoscope* to demonstrate its potential of advancing from the current state of the art.

As mentioned in the introduction, this project was initiated by both a real-world problem about accumulating digital photos and a goal of exploring innovative ways to build people's long-term intimacy with their photo archives. From this, *relevance* is achieved as *Chronoscope* was designed to fit in a domestic context and created as a

vehicle to embody temporal relations among digital photos in its visual representation and tangible design. Without an actual artifact to interact with, it is exceedingly challenging for people to make sense of how big their digital photo archive is and how their photos could relate to each other in a much more macro view. Hence, a *preferred state* was explored through the *Chronoscope* design to enable a potentially more curious, reflective and engaging experience with vast digital photo archives.

In terms of *extensibility*, the insights derived from *Chronoscope* are applicable to future interaction design research. Our inquiry led to *interaction qualities* that allow people to explore their digital possessions with ease and pleasure and grow more lasting and interactive relationships with them. The *temporal design features* could also inspire more application and development of any digital material that has timestamp embedded in its file format. Overall, these insights were provided with an aim to open up new possibilities in future research.

In sum, our designer-research approach relies heavily on RtD as a research method that uses design artifacts as instruments to ask questions and test ideas. The four RtD lenses (above) directly shaped the ways we connected *Chronoscope* to a real-world problem and communicated its value to the broader research design research community. Next, we unpack details into how our *process* was guided through first-person experiences shared among the design research team.

Autobiographical design

While our practice-led designer-researcher approach shares some similarities with First-Person and Autobiographical Design (AD) approaches [e.g., 148,190], there are still some notable differences. Neustaeder and Sengers characterize autobiographical design as ‘design research drawing on extensive, genuine usage by those creating or building a system’ [148:154]. It focuses on the genuine needs of researchers, which embody their own experiences in the system design and concept exploration through a cycle of *building*, *learning*, *evaluating* and *iterating* the design. While facing a challenge of reporting with objectivity, AD has benefits that include shortening the feedback cycle, anticipating and solving key issues before testing the design with research participants in field, and uncovering the nuanced understandings of one’s lived experience with the design artifact. AD is conducted by a single researcher, although others may also be present in the research (e.g., such as the researcher’s

family members). In contrast with AD, our designer-researcher approach involves four special focuses:

- *originality* — initiating an idea that emerged from personal expertise and research trajectories,
- *diversity* — forming a small but interdisciplinary team to ensure the quality of design artifacts,
- *provocativeness* — pursuing both robustness and creativity reflexively through crafting and living with design artifacts, and
- *unity* — having a unified narrative voice to report our research outcomes.

While AD emphasizes the genuine usage and exploration cycle in the long-term testing part, our approach values it and the technology creation part equally. Therefore, new ideas usually originate from design researchers' expertise in certain design materials and relate heavily to their own research trajectories. With a background in Computer Science and special focus on digital photos, Amy Yo Sue Chen (co-author) joined Everyday Design Studio in 2017 as a Ph.D. student supervised by William Odom (co-author), who co-directs the academic design studio and has investigated slow technology as a lens to design new kinds of experiences with photographs, music, and other digital media for several years. Motivated by the *Photobox* [160], *CrescendoMessage* [222], and *Olo Radio* prototype [158], we (Chen and Odom) started the discussion of the *Chronoscope* project with an idea of having a handheld telescope-like form as an alternative way to interact with digital photo collections. Without our research backgrounds, expertise, and positionality of accumulated works as key factors, we would not have initiated this difficult RtD project, however, because of it we felt positively that it would produce new knowledge that could only be explored through new design.

However, producing a highly resolved design artifact is not easy. In the *Chronoscope* project, we needed to involve other investigators and research assistants with expertise in electronics prototyping, form design, and digital fabrication to create the artifacts. By co-leading a small but interdisciplinary team, we were able to circulate thoughts and exchange *diverse* perspectives to overcome challenges. We see our designer-researcher approach as *reflexive* and with the goal of delivering first-hand insights through ongoing individual and collective design practice, group critiques, material explorations, experiences of living with prototypes collectively in our studio as

well as individually in our own homes. In addition to AD's core concept of trouble-shooting and iterating systems in their personal use and living with the design artifacts, our approach pursues unexpected but desired design features for longer-term lived experience that could not be imagined or foreseen without design researchers' keen observation and criticality. The sensitivity used to explore the design comes from both deep understanding of the design itself by the researchers, and the intuition to critique and make changes as designers.

While embracing the benefits of having a wider range of expertise and opinions, a designer-researcher approach has a particular challenge of reporting research outcome in a *unified* narrative voice across our design team. Hence, our approach requires one or two project leaders to constantly synthesize perspectives and distill insights from the various, creative understandings among the team members. The attachment between researchers and the system design is formed through not only the individual practice-based creation process but numerous collaborative discussions. We see this challenge as the most important part as it shapes how our first-person approach is interpreted and presented to the research communities.

Building on the first person-oriented nature of AD, the designer-researcher approach offers a related but different way form of practice-based research. Although the designer-research approach requires extra work to unify voices across the design team, we find that this most challenging part to also be the most rewarding. This reflexive process itself requires project leaders to reflect on their original goal which can catalyze additional insights and research opportunities. Next, we talk about how *invention* comes into being in details.

Reflective conversation with materials

To begin our design research inquiry of *Chronoscope*, we explored potential design materials that pertain specifically to the temporal metadata in digital photos. We initiate our observation by virtue of trust in a reflective, practice-based process. We believe:

> the designer-researcher approach can contribute a highly insightful, first-hand, and reflexive view of practices of making design artifacts in relation to higher-level concepts framing key decisions in the design process and in light of attendant materials, tools, methods, and competencies. [155]

We see this approach as highly aligned with Schön and Bennet's characterization of design practice as *a reflective conversation with materials* [200]. A designer-researcher approach to practice-based research heavily emphasizes a designer's knowing-in-action that involves sensory and bodily understanding in relation to the team's evolving understanding of materials. This is a recurring process where the materials 'talk back' through a back-and-forth process that progressively leads to a refined understanding of the overall design and, ultimately, the final resolved design artifact. This approach gives prominence to first-hand insights that emerge through iteratively working with materials to ground conceptual ideas through the creation of new things: 'a process of moving from the universal, general and particular to the ultimate particular – the specific design' [147:33].

In the *Chronoscope* project, the 'material' we worked with came in the form of digital photos and their attendant metadata, which are a series of information encoded into each digital photo at the moment the file is created. The digital photo metadata material includes information such as the camera specifications, geolocation, image size and compression style, and the timestamp capturing when the photo was created. We were most interested in 'speaking to' the timestamp data because it stands as a potential medium that provokes a tracing and reasoning experience of specific memories.

Timestamp is numeric and sequential in its nature, and the way to make use of this type of data requires a specified format (e.g., YYYY/MM/DD). From observing how various formats frame our cognitive understanding to systematically absorb and compare those photo content in a list view, we arrived at a linear 'timeline' design that visualizes clear *Sequential Events*. We rapidly programmed an interactive Processing script and an iOS mobile application as prototypes in order to automatically capture, structure, and organize digital photos chronologically. By giving prominence to the presence of temporality hidden in every digital photo as an anchor point to make sense of the sorting order, we were enabled to actually see the possibly consequential connections between photos, and explore those connections through moving the photo collection backward or forward in time. This back-and-forth visual interaction provides a clear pathway for each specific photo memory to 'talk back' to us not just about their relative location in time but their relations to other photo stories in a macro level.

However, the mere chronological timeline design felt somewhat limited and underwhelming. On one hand, the linear photo collection on the prototype have ends on both sides and therefore does not provide a sense of continuity to encourage exploration. On the other hand, those photo memories flow in an order of how we exactly experienced and remembered them. Crucially, the Processing prototype enabled us to quickly move across a large number of photos in an archive and simultaneously saw timestamp information separated by time of day and date. The separation of information not only prompted us to stimulate recollection of past experiences peripheral to the central photo but also triggered our imagination of having non-chronological 'timeframe modes' that reorganize photos *across* the archive based on existing meaningful temporal patterns. Built upon prior works that have discussed how clock time [135] and digital time [193] have reframed the personal and collective rhythms of everyday life, we brainstormed in designing non-chronological ways of photo viewing that offer multilayer and cyclical perspectives (based on Date or Time of the Day, irrespective of Year). Our interest in this notably wider spectrum of potential interactions is in part inspired by the concept of *ecphoria* [225,226] which refers to the experience of recalling a fuzzy or entirely forgotten memory when prompted by sensory input – in our case, digital photos from one's past. In a nutshell, the gist of having a reflective conversation with materials includes three parts:

- understanding the nature of design materials,
- exploring various forms and expressions made of the materials, and
- observing the interaction dynamics with appropriate tools.

We arrived at the final design features of *Chronoscope* that may not be achieved without the powerful computing tools' support to our dialogue with the materials that bring potential experience design to reflection and curiosity through and across personal memories. Next, we discuss the benefits of shaping a design artifact into a Research Product.

Research product

In our design research studio, we polish our design artifacts to become *research products* (Odom et al. 2016) that fully support the final and actual deployment in the complex real-world setting to inquire research questions. Research products are intended to be lived with over longer-time periods and achieve a high quality of fit in, and

among, things in people's everyday environments. Thus, a key part of this process involves different design team members living with various prototype versions of the design artifacts we are making to fine-tune qualities of use (e.g., the pacing or rhythm of a slowly changing system), exploring living with different forms and materials, and field testing for technical robustness. To put it concisely, there are two critical steps in the framework of *research product*:

- creating a highly finished research product that functions and lasts in an everyday context
- living with the research product over a long period of time

In order to inquire how people exactly experience *Chronoscope* and their relationship with it over time, a tangible version was created with full functionality for the everyday, rather than laboratory/ studio, context. We loaded programming code to a microcontroller board that controls electronic components such as a tiny display, three rotational actuators, and a light-weight battery. To store them in a small size form that best supports handholding, we meticulously designed the interior space of the scope and outsourced the 3D printing to a more professional service provider to achieve the highest resolution. This design process required numerous group discussion but also very personal moments of cultivating the sensitivity of feeling how tangible rotation manipulate the reaction of photos showing on the tiny display embedded in the scope. Through countless trouble-shooting and fine-tuning in the iterations, we arrive at a robust and highly finished version of *Chronoscope*.

Before we deploy it to people's houses, our design team members lived with the product over a long period of time, and made adjustments to counteract the frictions we encountered. The first friction was related to the sheer size of the photo archive. For instance, when a user has 20,000 photos and she aims to navigate to a specific time of her photo collection, it would take her about 2.77 hours to get there since each rotation moves through the photo archive by only one photo as a unit (and it takes about 0.5 second per rotation) this led to a sensation of being '*stuck in time*'. This issue would very likely complicate people's ability to form long-term relations to *Chronoscope* and hinder our aim of making it a research product. This friction triggered our decision to include blending as a support for 'tuning' the number of photos (or *granularity*) that one moved through for each rotation. With this support, people could move through their photo

archives in very slow, precise and considered ways (i.e., 1 photo per rotation) to encounter a set of photos that triggered deep reflection or examination, or equally, quick move across vast amounts of photos without an excessive amount of rotations, while retaining a subtle awareness of what had been passed over (i.e., 100 photos per rotation). In order to solve the friction, the added 'tuning' feature opens up more freedom and flexibility for the user to move through photos from minutes in a day to years of one's life.

As the research product was designed to be a slow technology (see above), it is very likely that the artifact would be experienced differently as time passes by, and as researchers we need to negotiate this factor in order to make sense of micro-interaction. As a slow technology design takes time to understand and gradually evolved over time, *Chronoscope* introduced other challenges of the granularity control. If the upper threshold was too high, then a user could easily become '*lost in time'* as they navigated a large amount of photo in one turn (i.e., effectively flashing ahead into the future or back into the past without a clear point of reference). Through an iterative process, we determined that by setting upper and lower boundaries of the granularity helped mitigate these design issues in support of our higher-level goal of manifesting different forms of time in support of ongoing reflective experiences. However, such boundaries need to be dynamically alterable and able to evolve with the photo archive as it continues to grow over time. Our design team went through several rounds of prototyping with different types of interactions, forms, and levels of fidelity of the interface to arrive at thresholds that seem suitable to the modern average size of digital archives.

While the four points in our designer-researcher approach gives a foundation for making high-level decisions across all of our research projects, each project never quite follows the same pathway to form a unified narrative voice from synthesizing perspectives and experiences across the design team. Our overarching goal in the *Chronoscope* project was to contribute concrete insights into unpacking how diverse temporal interactions might be designed with personal data through the form of an everyday artifact that is intended to be lived-with over time. In this, we have emphasized where its key theoretical, methodological, and practical challenges emerged and our design moves to resolve them.

4.4. Discussion and conclusion

In this chapter, our piecemeal, practice-based designer-research approach enabled us to create a design artifact that extended core approaches to designing slow technologies by building in a high degree of end user control, while retaining design qualities that are closely tied to the original conceptual vision of slow technology. The case of Chronoscope illustrates that future practice-based approaches to crafting slowness and temporality into new artifacts may require added time for reflection and adaption that may be counter to the often frenetic, time-constrained norms of contemporary interaction design practice. This methodological insight is revealing about the need for design practice to evolve and is also reflective of the original vision of slow technology:

> As computers are increasingly woven into the fabric of everyday life, interaction design may have to change – from creating only fast and efficient tools to be used during a limited time in specific situations, to creating technology that surrounds us and therefore is a part of our activities for long periods of time [85:201].

We have described and reflected on how slow artifacts can provide alternatives to how we might conceptualize supporting longer-term relations to our everyday technologies and personal data – and how such inquiries can be grounded in design practice. However, without our designer-researcher approach, the discoveries and insights would not have arisen.

Ultimately, this chapter describe our designer-researcher approach and offer a reflection on how its four critical points – research through design, autobiographical design, reflective conversation with materials, and research product – could be exemplified through unpacking the process of crafting a design case. From these four points as keys to developing the practice-based insights, we would like to offer four takeaways of what practice-based research usually involves:

- shaping and manifesting the research questions and proposals into practices
- first-person perspectives both as an individual and a team
- deep reflection on the resources and people's perception of them

- adapting the practices to real-world contexts and negotiating them when friction arises

In conclusion, an additional goal here in this chapter is to help readers to take a step toward understanding how our designer-researcher approach could potentially be applied and explored in their own fields. We see opportunities for bringing together philosophers and social scientists who explore differing theories of temporality with practitioners who are skilled in manipulating temporal media (e.g., musicians, composers, poets, new media artists, etc.) to collectively develop new ways of grounding theoretical concepts related to time through creative practice. Ultimately, we hope our research methods can support future practice-based initiatives that are aimed at investigating the complex and evolving subject of human relations with technology over time.

Chapter 5.

Exploring Memory-Oriented Interactions with Digital Photos In and Across Time: A Field Study of Chronoscope

5.1. Overview

The research captured in the previous chapter reinforced my attitude as a design researcher and supported me to think through how our piecemeal designer-researcher approach led to the final version of Chronoscope artifact. Through unpacking this designer-researcher approach, we started to see Chronoscope as a slow technology design case that offers a high degree of user control while retaining design qualities that are closely tied to the original conceptual vision of slow technology. We would not have arrived at Chronoscope's final version and the insights in relation to temporal granularity without the piecemeal, iterative, and first-person practice-based design approach. However, despite the benefits and opportunities of this approach, the research outcome is still limited to our own experiences of using Chronoscope in the design team.

To better understand people's situated experiences of Chronoscope, we were inspired to conduct an empirical study. We decided to create and deploy a batch of 4 Chronoscope research products to 4 participants' houses for 3 months in order to understand people's longer-term lived experiences with Chronoscope in field[3]. The research question that is investigated through this field study is:

RQ3: What memory-oriented photo viewing experiences could be supported and sustained through a tangible photo viewer that allows people to explore their digital photos chronologically and non-chronologically?

Next, I unpack the details into this field study.

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[3] This chapter is adapted from a publication in CHI'23: Amy Yo Sue Chen, William Odom, Carman Neustaedter, Ce Zhong, and Henry Lin. 2023. Exploring Memory-Oriented Interactions with Digital Photos In and Across Time: A Field Study of Chronoscope. In Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, Association for Computing Machinery, New York, NY, USA, 1–20. DOI:https://doi.org/10.1145/3544548.3581012

Figure 18: A use scenario of Chronoscope
From Left to Right: The Chronoscope in Alice's bedroom during the deployment; Peering into the scope, the user views photos from her past. Her left hand manipulates a fully rotational gray silicon surface (rotating clockwise moves 'forward' in time and rotating counter-clockwise goes deeper into the past); The display inside visualizes the central photo's location in time and provides corresponding data; Its user interface includes the central photo, its timestamp on the top left, its location data, and the current mode it is in. The user can rotate the scope to move along the photo collection to the right (closer to the present in time), or to the left (back into the past).

5.2. Introduction

Since their emergence in the 19th century, photographs have operated as resources to support people's practices of self-reflection, social interaction, identity construction, and contemplation of the future [12,38,245]. Today, people's photographic practices are highly mediated by digital devices and services. These digital technologies have enabled people to accumulate personal photo archives at scales larger than ever before. For instance, it is estimated that 1.72 trillion photos are now taken worldwide annually, and 89% of the photos were taken with smartphones [24].

These massive and still growing digital archives pose new challenges for the Human-Computer Interaction (HCI) community. As people's digital photo archives continually grow larger, they become formless and placeless, lacking the material presence that might invite people to notice and engage with their archive as a resource available in their everyday lives [161,215,245]. This tension can also introduce challenges for people to grasp how expansive their digital photo archives are and what experiences, histories, and things are documented within them [170]. Recent research has shown that the widespread adoption of smartphones and low-cost availability of cloud storage over the past decade has accelerated the growth of personal photo archives [15], which further amplifies existing tensions. These shifts also generate new opportunities for people to reflect on memories bound up in their photo archives that document a considerable breadth and depth of life experiences over numerous years. However, there is limited knowledge on what strategies or concepts could help guide design research to better support and sustain reflective experiences with large photo

archives. Growing work in HCI has argued there is a need to develop alternative design approaches that better support open-ended experiences of reflection, interpretation, and slowness when revisiting their digital photos archives (e.g., [54,95,162,222,223,230]). In parallel, as interactive technologies have become embedded in people's everyday lives, researchers have proposed it is necessary 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." [136:11] Yet, 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 precisely to this intersection through investigating three main objectives. First, we want to inquire into how making people's digital photo archives more materially present and interactive with different temporal modalities might open new possibilities for reflective memory-oriented photo viewing; in this, we attend to how photos work as cues that trigger autobiographical memory in situ. Second, we aim to better understand how temporal metadata could operate as a resource for potentially generating a renewed sense of awareness and control over large and still growing personal digital photo archives. Third, we want to pursue personal life history as an aspect of temporality raised by *slow technology* [85,163] and inquire into how this framing might offer a rich way to support experiences with digital photo archives that change over time. To this end, we aim to empirically explore conceptual propositions related to slow technology design theory.

To pursue these research goals, we conducted a three-month field study of *Chronoscope*—a design artifact that leverages the timestamp metadata attributed to each photo from when it was originally taken to open up new ways of experiencing the lifetime of digital photos in a person's archive (see Figure 18). Motivated by prior research on slowness and temporal design [84,136,163], key qualities of Chronoscope's design include: *takes time to understand*; *manifests change through time*; *modulates pacing of sequential movement through time;* and *generates interconnections across different forms of time to prompt reflection on their presence in everyday life*.

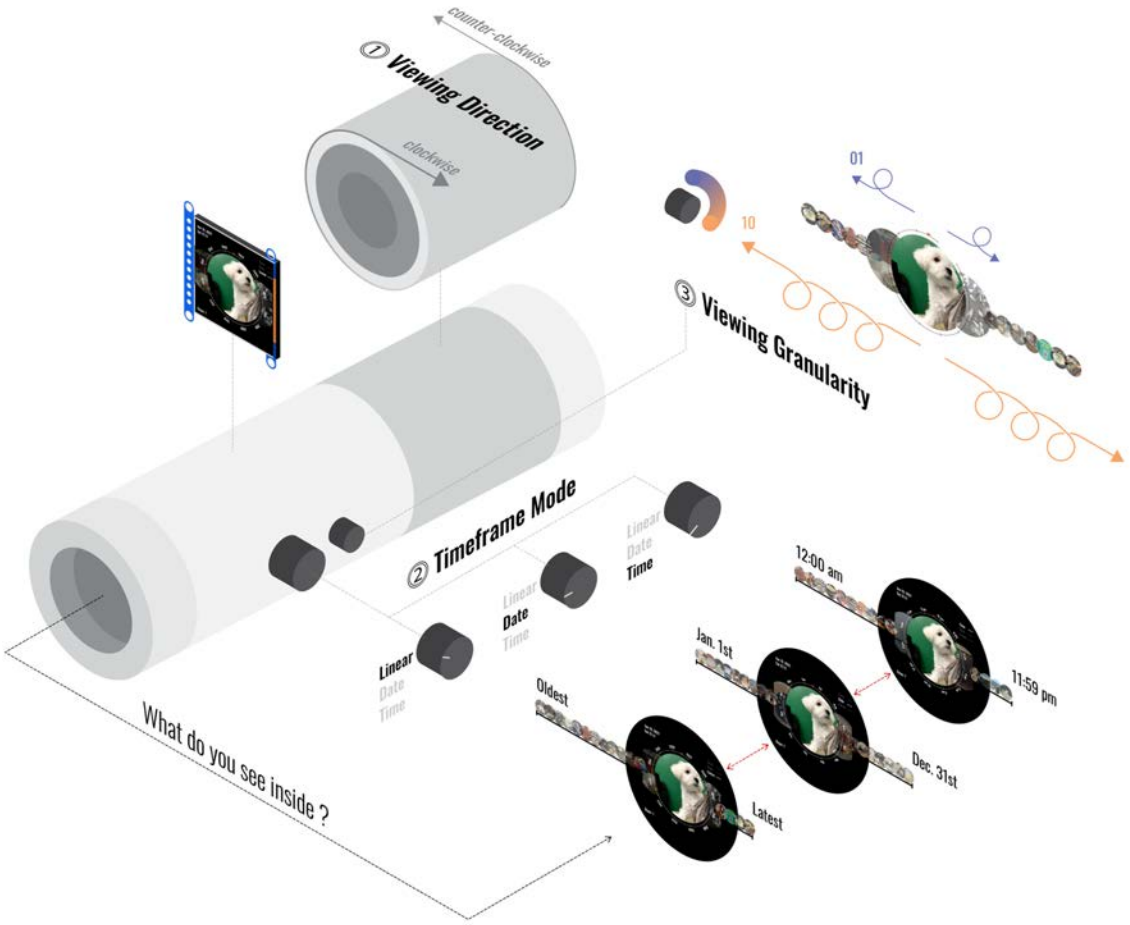


Figure 19: There are three physical controls that work together to enable a user to explore their photos in and across time (and they dictate what is shown on the embedded display).

① The viewing direction is decided by which direction the wheel is rotated (either clockwise to more recent photos, or counter-clockwise to older ones with the selected timefame) ② The timeframe mode (Linear, Date or Time) is selected by the larger black knob. ③ The smaller viewing granularity knob controls how many photos the user navigates across in a single rotation within the selected mode. In the lowest setting, 1 photo and at the highest 10 photos are moved through; this applies in clockwise or counter-clockwise movements.

Taking inspiration from the focal way people use scope-like objects, Chronoscope is a near eye interactive photo viewer that enables users to revisit, navigate, explore, and contemplate the various memories bound up in their personal photo archives across time. As shown in Figure 19, a cornerstone of the Chronoscope design is its three interconnected timeframe modes that enables the user to organize and interact with their digital photos through chronological (*Linear*) and non-chronological (*Date, Time*) forms of time. Importantly, when a new mode is selected, the center photo-in-view does not change, while the surrounding photos are replaced with ones from the new timeframe. This, in effect, enables the photo-in-view to operate as a

kind of anchor point that creates interconnections across different timeframe modes. Chronoscope offers direct control to the user to change the timeframe modes and the position ‘in time’ within their photo archive whenever desired. This creates an opportunity for the user to explore a range of possible connections across different photos taken at different points in time in their past. Yet, Chronoscope’s design remains relatively minimal. It takes time to understand, recognize, and interpret memories bound up in one’s massive and still growing digital photo archive.

We created a batch of four Chronoscope *research products* [168] and deployed them in four households for three months, using them to open a dialogue with participants about the open-ended, reflective potentialities of memory-oriented photo viewing technology; and, to probe on their experiences of living with this design artifact over time through the lens of slow technology. Findings revealed that Chronoscope became integrated into participants’ everyday practices and catalyzed a range of reflective experiences on their respective life histories and life stories. They also showed that perceptions of Chronoscope subtly 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 artifact can support memory-oriented photo viewing by making one’s digital photo archive accessible through different temporal modalities. Second, it offers a case that helps expand strategies for designing slow technologies that can be accepted into people’s lives and change with them through time.

5.3. Literature review

The related work falls into four sections: digital photos, memory studies, personal data, and slow expression.

Digital photos and interactive systems

Digital photographs have existed for decades and represent one of the most prevalent and extensive forms of digital possessions that people have. Thus, it is perhaps no surprise that digital photos have received considerable attention in the HCI community and, more broadly, the social sciences and humanities. Numerous researchers have described the varied roles digital photos play in supporting identity construction (e.g., [40,41,89,236]) self-growth (e.g., [39,131,234]), practices of personal

and collective remembering [5,21,45,46,145,235], as well as developing a cohesive life story over time [6,92,93,197,198]. HCI researchers have also long been interested in how people's everyday interactions with digital photo capture, storage, and organization could be improved (e.g., [65,115,234,236]).

Despite the valuable and diverse resources that digital photo archives can offer, the exponential growth of digital photos has made it difficult for people to access and engage with their vast collections [22,245]. Recent research by Bergman et al. [15] has shown that the adoption of smartphone has only exacerbated these difficulties as the production and proliferation digital photos continues to expand. Research has also shown design strategies for navigating large archives commonly mobilized in contemporary photo applications, such as long scrolling galleries of photos, are not effective prompts for remembering past memories [22]. Scrolling galleries require photos to be opened to full screen before they can be fully recognized, which interrupts the experiential flow of browsing, thus limiting the capacity for reminiscence [5]. Other common strategies, like digital slideshows, overcome this tension by displaying photos in higher resolution, but introduce different complications—showing only one photo at a time can cause people to lose the narrative context across the photo set which limits person-centered and episodic forms of remembering [2,5]. Further, slideshows require a subset of photos to first be curated from a large collection which diminishes capacity for spontaneous and serendipitous remembering experiences [5]; and, more generally, people tend to abandon efforts to manually curate digital photos [15].

Design researchers have begun to investigate strategies to address these complex tensions and better support interactions with people's photo archives that can scale over time. One key strand of research has focused on investigating how tangible interactions can be designed with personal digital photo archives [8,95,139,162,246]. A limited selection of design research projects, such as Photobox [162], ReFind [241], Memora [91], Photoswitch [52,53], and Fenestra [227], have shown the value of increasing the physical presence of digital photos in people's everyday lives through the creation of new design artifacts. These works have begun to illustrate how the combined qualities of form, materials, and interaction can lead to increased interactions with and perceived value of their digital photo archives as well as with the design artifact itself. Yet, they only focused on resurfacing a single or a small subset of photos in people's life. Another major HCI research area has focused on how tangible interactions with

digital photo archives can generate alternative ways to support open-ended experiences, such as locating and sharing memories with digital photos (e.g., [109,230]), catalyzing social conversations (e.g., [87,95,222]), and supporting both individual and social experiences of reminiscence and reflection (e.g., [162,174,222,228,246]).

Other more recent HCI research has focused on creating interaction technologies for digital photos which include AR-enabled tangible photo viewing [27,83], two-sided formats for digital photos [81], and novel approaches for supporting photo taking practices such as selfies (e.g., [105,221]). While most of this research focuses on use-cases involving individual photos or a small number of photos from the recent past, metadata has begun to be explored as a resource for augmenting human-photo interactions with added contextual factors. Tactics such as vote-based photo curation [249], environment-based remembering and searching techniques [97], and multidimensional visualization of photo collections [102] have each been investigated to limited degrees, respectively. These investigations are largely motivated by a practical need to manage and organize digital photos. Yet, few works have explored how metadata, as a context provider, could be used to support more diverse forms of photo viewing and interaction.

Overall, these collective works indicate that, while limited, there is growing interest in exploring new and novel ways to engage people's digital photo viewing experience. They also show the real and complex frictions that come with massive personal digital photo archives, highlighting the need for a multiplicity of approaches that can enable people to get a grasp on their archive and re-experience the memories bound up within it. Our research aims to extend these works by deploying and studying a novel system that supports rich, open-ended interactions with personal photo archives through and across time.

Memory cues and autobiographical memory

At the intersection of HCI and memory studies, photographs have been investigated as powerful memory cues for autobiographical memory. They are often considered as information resources that aid people in remembering and retrieving key contextual details of a memory tied to one's personal history [196,204]. Research investigating memory cues has increasingly gained purchase within interaction design, with a particular focus on *external memory cues* – "physical or digital cues in tangible

embodiment with an internal effect on memory reconstruction" [100:110]. Often initiated by memory cues, autobiographical memory is "memory for the events of one's life […] where considerations relating to self, emotion, goals, and personal meanings, all intersect" [34:103]. Taking these concepts in mind, we can see one's personal digital photos as an archive with a growing number of memory cues in it that support people in retrieving memories that, in part, construct their life history [99,143]. Most contemporary digital photo applications and storage services have been designed to support voluntary recall of autobiographical memories that "follow a controlled, strategic retrieval process" [16:279] which involves considerable amounts of intentional searching, editing, and repurposing techniques for photos. Yet, involuntary autobiographical memories, such as seeing a picture with high school friends on a bedroom wall with no preceding attempt at memory retrieval, have been found equally frequent and important in supporting people's everyday remembering processes [192]. People's experience of remembering can be seen as a situated and constructive process [10], and tangible memory cues existing in people's living environments have been found highly effective in triggering involuntary autobiographical memories [16,99].

Against this backdrop, our research aims to extend this work through investigating the potential and limits of temporal metadata as a type of external memory cue. We explore how a time-based retrospective remembering process might be enabled and supported through leveraging temporal metadata as the key design material shaping interactions and experiences with digital photos. We want to inquire into how different kinds of temporal contextual cues may help situate and interweave digital photos across one's personal history. Thus, we contribute a field study detailing how rematerializing and reorganizing digital photos through a temporal lens shapes people's situated experiences of reconstructing autobiographical memories in their home.

Personal data, history and revisitation

The HCI community has had an ongoing interest in how personal data can be represented to support reflection on personal everyday experiences [36,56,82,170,189] and life histories [35,55,98] in ways that are open to ongoing interpretation [195]. Prior work has focused on the design of technologies that extend data, such as images or audio recordings, to physical cherished objects (e.g., [67,151,171,175]). Researchers

have also begun to explore opportunities for enabling people to re-experience digital media from their past with photos, music, and social media (e.g., [98,113,167,218,219,223]). Over the past several years, HCI and design researchers have articulated new opportunities for using metadata "as a resource for people to manipulate and personalize their virtual possessions" [170:991]. Through the Curatorial Agents project, Gulotta et al. proposed that temporal metadata in particular 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." [82:3460] Collectively, this research helped open opportunities for seeing metadata in a new way for design – not simply as a byproduct 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. Elsden et al. argue there is a need to investigate the design of interactions with personal data that expand beyond "an exclusive interest in performance, efficiency, and rational [self] analysis" [57:48] and that emphasize interactions with personal data "representations that support multiple perspectives rather than reductive explanations" [57:47]. Elsden and colleagues later extend this work to articulate the design approach Documentary Informatics [54] where they propose key opportunities for future research: (i) exploring the role that data could play in shifting orientations to photography as a technology of memory [235] and (ii) giving data a fixed form to enable it to settle in place [216] as an ongoing part of everyday rituals and practices.

Leveraging different kinds of metadata as filters to supporting alternative ways of data *wayfaring* [189] has also been proposed as a key opportunity area for generating new ways of reflectively orienting to key events, threads of history, and lifelong practices bound up in large archives of personal data [57]. Nascent design research has begun to show the promise of creating new technologies capable of supporting more nuanced and alternative interpretations of personal data in ways that can grow and change over time. The Olo Radio project [158,169] explored how metadata could be a resource used to reorganize and re-surface music that had been previously listened to in one's past through different forms of time. This work opened new ideas about how metadata could be a design material for supporting memory-oriented interactions with digital media from one's past in open-ended ways. The design and study of Slide2Remember unpacked how a wall-mounted photo viewer could randomly shows a user's photo paired with a

song that was listened around the same time when the photo was taken [114]. This project demonstrated how pairing two forms of personal digital media that were bound to a similar point in time can support situated experiences of reminiscence. In both instances, by emphasizing the *presence*, *coexistence*, and even *sequence of* different digital instances based on their creation date, these design cases showed how to use temporal metadata as a strong resource to reorganize, resurface, and reconnect people with their personal life history more meaningfully. Yet, to date very limited research on metadata exists in the context of digital photos.

Our work seeks to directly build on this prior research and contribute a field study investigating how temporal metadata, embodied through Chronoscope, instantiates a 'place' to have open-ended experiences with vast personal digital photo archives. We discuss opportunities for memory-oriented photo archive interactions and 'wayfaring' through a temporal lens, and the roles that alternative representations of personal data could play in opening a space for exploring one's life history from different perspectives over time.

Designing for slowness and temporality

Bound up in a personal digital photo archive, the scale and depth of different points in one's life history are what motivated us to explore how digital photos could be re-experienced through a diverse temporal lens. In their foundational research on *slow technology*, Hallnäs and Redström proposed "a design agenda for technology aimed at reflection and moments of mental rest rather than efficiency in performance" [85:201]. This vision was extended through the critical argument 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" [85:203] and "…that will last and develop over time" [136:11]. Since these foundational works, there has been a growing interest in exploring slowness and temporality as frames for the design of new technologies. Galani and Clarke [70] applied a slow technology framework to catalyze imaginative experiences through an augmented reality museum installation. Grosse-Hering et al.'s Slow Juicer [80] and Pschetz and Banks' Long Living Chair [180] each mobilized slowness to give rise to meaningful reflections on embodied practices with each artifact respectively, and prompt reflection their one's relation to them over their lifetime. Taking

an analytical approach, Huang and Stolterman [101] utilized visual representation to examine temporal patterns and usage.

A handful of works have explored how slowness could support meaningful experiences with digital data. Examples including the Reflexive Printer [223], Photobox [162], Olly [167], and Postulator [87] 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 high level aspirations of slow technology through design in ways that offer people some control over the system, while not compromising the richness of this approach [163,169,179,181,222]. Pschetz and colleagues [20,181] offer a salient argument that projects aimed at designing for slowness may result in an oversimplification of the dichotomy between fast and slow by treating 'time' as solely a matter of pacing. Extending this argument, Rapp [184] 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 Chronoscope, we want to explore how chronological and non-chronological expressions of time can be used as frames to engage people and design temporally diverse interactions with vast digital photo archives.

5.4. Methodology

The previous work of Chen et al. [31] unpacked the initial design of Chronoscope, but the artifact was not fully resolved. We build on their work by conducting a long-term field study of people's experiences with a highly finished version of this device. Instead of taking a user-centered design approach that often makes design iterations based on a small number of short-term laboratory results, we adopt the concept of *research products* [28,168]–design artifacts that are created to drive a research inquiry in a real-world context and that have a high quality of finish such that

people engage with them over time as is (i.e., a thing), rather than what they might become (i.e., a prototype). Research products are created to operate independently for substantial time periods to support long-term field studies in people's daily environments. In extending prior work, we created a batch of new Chronoscope research products that are highly robust and resolved. Next, we summarize key parts of our design process to highlight important qualities of our final version of Chronoscope.

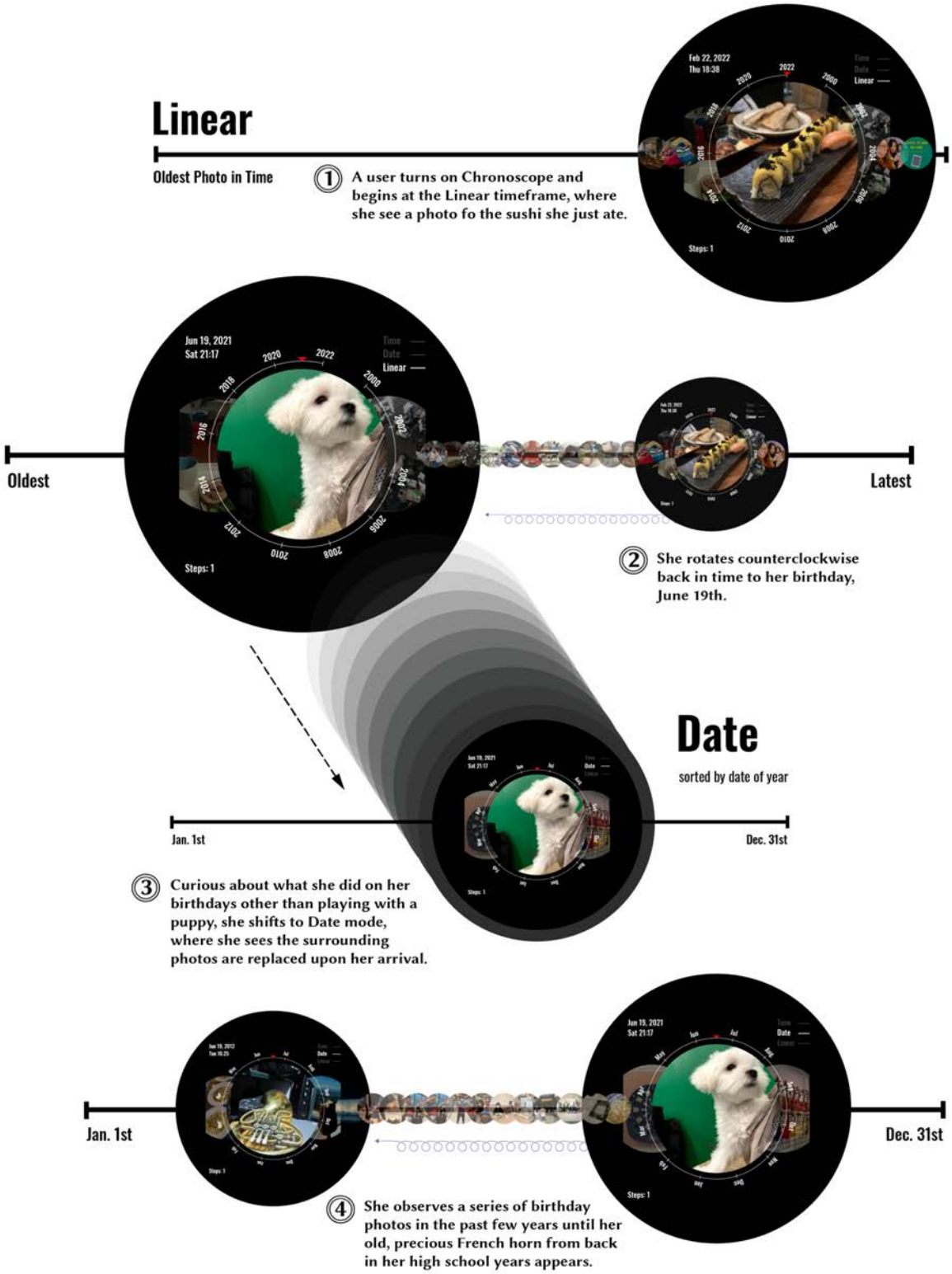
5.4.1. Design process and implementation

Our own framing and design of Chronoscope is influenced by conceptual propositions that we arrived at through close readings of the theoretical articles on slow technology [84,136,163]. An abbreviated and synthesized set of propositions that shaped our framing are as follows. Slow Technology is a technology that: *takes time to understand*; *manifests change through time*; *modulates pacing of movement through time;* and *generates interconnections across time in everyday life*. In line with these conceptual aspirations and inspired by recent work that extends a theory of slow technology for design, we are interested in building in support for controlling *temporal modalities* – where "the integration of one or multiple different forms of time are the cornerstone of an artifact's interaction design" [163:174] – and *temporal interconnections* — which "opens the possibility for interconnections to form and expand across all instances of digital media or data embodied by a design artifact across multiple dimensions of time" [163:174]. Prior research has speculated that these conceptual propositions may come together to "project a co-evolving quality that is unique and distinct to the user, that takes time to interpret, and that can scale to evoke cumulative change over time" [163:174]. We want to understand how these design qualities might shape participants experiences with Chronoscope over time in the context of their everyday lives with their actual personal digital photo archives. Next, we briefly elaborate on key parts of our design research process and field study.

Integrating temporal modalities and granularities

Chronoscope enables users to explore and interact with their photo archive through three combined rotational controls on *viewing directions*, *timeframe modes*, and *viewing granularity*. When peering into Chronoscope, a single photo tied to the specific time that it was originally taken will be visible (see Figure 20 for a full scenario of usage).

Figure 20: **Scenario of moving across the three timeframe modes. Please follow the numbers and read from top to bottom.**



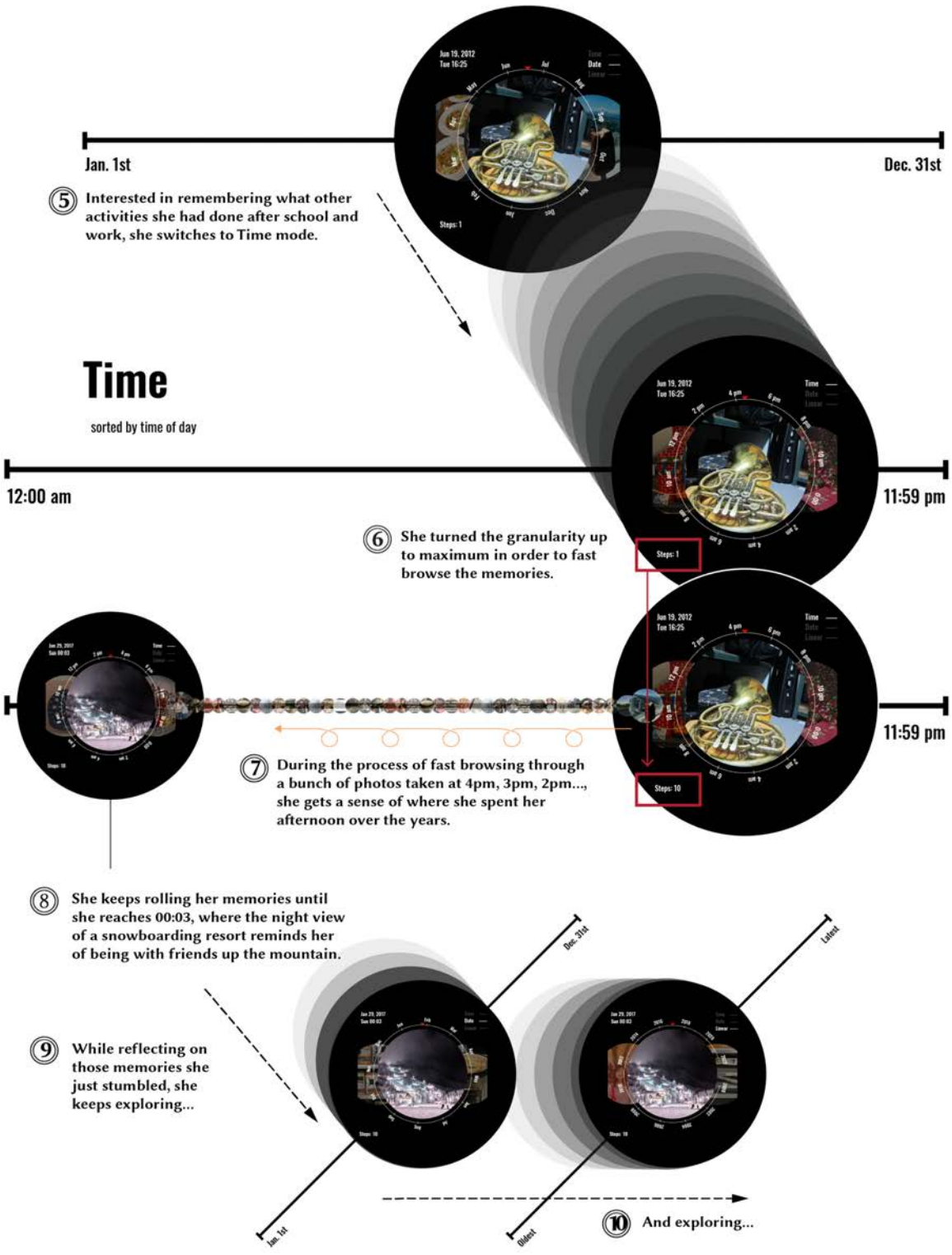

Jan. 1st
Dec. 31st
5 Interested in remembering what other activities she had done after school and work, she switches to Time mode.
Time
sorted by time of day
12:00 am
11:59 pm
6 She turned the granularity up to maximum in order to fast browse the memories.
11:59 pm
7 During the process of fast browsing through a bunch of photos taken at 4pm, 3pm, 2pm..., she gets a sense of where she spent her afternoon over the years.
8 She keeps rolling her memories until she reaches 00:03, where the night view of a snowboarding resort reminds her of being with friends up the mountain.
9 While reflecting on those memories she just stumbled, she keeps exploring...
Dec. 31st
Latest
Jan. 1st
Oldest
10 And exploring...

Figure 21: Four Chronoscope research products with color variations were created to support memory-oriented experiences with photos through different temporal qualities and by re-materialization of digital archive.

As Figure 21 shows, the scope's main feature is a rotating wheel that controls the *viewing direction*, navigating either forward or backward in time within the selected timeframe mode. Navigating in a timeframe mode occurs through a rotational movement (*clockwise* to move forward in time and *counterclockwise* to move backward). This form of physical rotation presents a subtle analogy to the circular shape of clocks and the seemingly perpetual, ongoing temporal flow evoked by their movement. By rotating either direction, the user sees each photo slide horizontally in relation to a wide spectrum of other photos in the archive. To 'speed up' or 'slow down' the amount of photos that are cycled through in one rotation when manipulating the *viewing direction* clockwise or counterclockwise, the user can adjust the smaller knob to 'tune' the granularity. This can, in effect, enable a user to move through their photo archives in very slow and meticulous manner if, for example, they encountered a set of photos that triggered deep reflection or examination. Equally, the control allows quick movement across vast amounts of photos without an excessive rotation, while retaining a subtle awareness of what had been passed over. This 'tuning' feature, termed *temporal granularity* [31,163], opens up more freedom and flexibility for the user to move through photos from minutes in a day to years of one's life.

When the user stops the rotation, Chronoscope settles on the specific photo associated with where 'in time' the position is in relation to the selected timeframe mode. When switching the bigger knob on the side of the scope, users can seamlessly toggle between different temporal organizations of their archive through three timeframe modes (*Linear, Date, Time*). *Linear* organizes in a linear timeline, from oldest to most recently taken. *Date* structures all photos in a temporal ordering based on the Month and Day they were taken irrespective of the year, potentially offering a more 'calendrical' way of exploring photos in one's archive. *Time* organizes all photos based on the specific time

of the day they were taken irrespective of date or year, opening a space to explore the rhythms and qualities of past experiences that cut across moments bound to parts of the daily 24-hour cycle.

Despite the three different types of controls, Chronoscope's experience design remains relatively minimal. It does not direct or point the user to a particular point in time. As more photos are accumulated in the user's everyday life, they continually form connections to different points in time across the three timeframe modes. The temporal granularity 'tuning' knob further extends control to enable the user people to develop a sensibility for their own desired interaction pacing when moving through time periods and across different interconnected points within their life history. Motivated by the need to *create technology that requires time to understand* and becomes part of people's practices over long time periods [136,163], the aim of these underlying decisions is to use minimal guidance for users in our final design in hopes of catalyzing a range of experiences that can scale and change as Chronoscope, and the photos manifested through it, are better relationally understood over time.

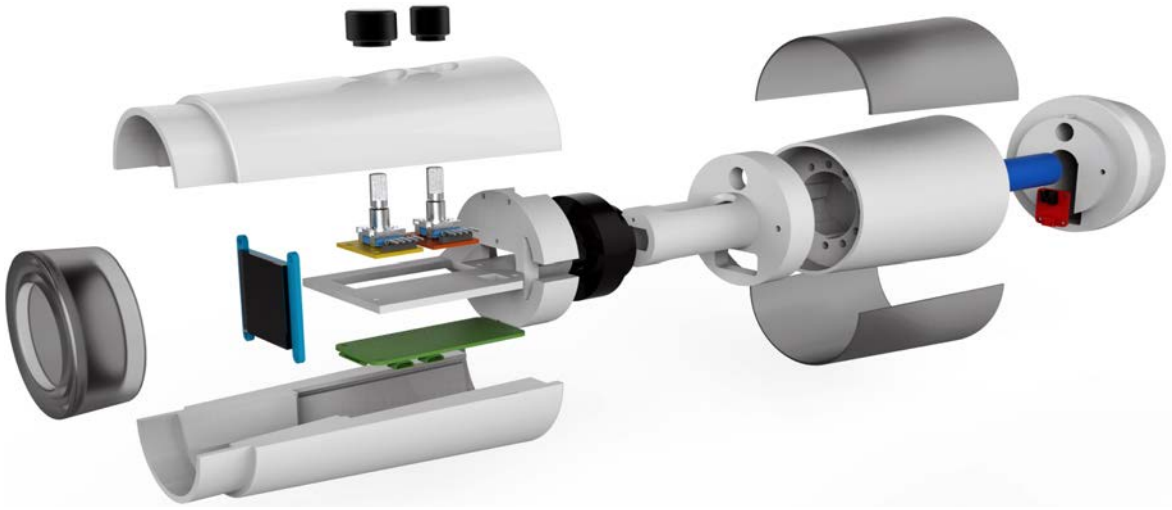


Figure 22: An exploded view of the final research product version of the Chronoscope design.
From left to right: silicone eyepiece with magnification lens is affixed to the 240x240 color display; Pi Zero W is integrated under a rotatry switch (for timeframe mode selection) and a potentiometer (for granularity selection); these compontents lead into a continuous rotary encoder that is integrated into a driveshaft (for photo viewing selection); a cylindical lithium ion battery, Powerboost 1000 charger, and latching pushbutton (for powering on and off) conclude the electronics implementation. The enclosure is fabricated from 3D printed Resin with the viewing direction rotational surface encased in silcone.

Crafting a small batch of Chronoscope research products

We crafted a batch of Chronoscope research products to investigate how different forms of temporal cues might shape people's real and situated experiences of recalling memories bound up in their personal digital photo archives. We started from a scope-like physical form because it critically suggests rotation-based tangible interaction and invites users to view and contemplate their past memories in an intentional, inquisitive way. Illustrated by Figure 22, we integrated a Raspberry PI Zero W that was connected to and controlled components that include one 1.54" TFT 240x240 color display that shows the user interface, one rotary encoder attached to the rotating wheel, one rotary switch that decides the timeframe mode, and one potentiometer that supported 'tuning' the temporal granularity. We also integrated a lithium ion cylindrical battery, a PowerBoost 1000 charger, and a latching pushbutton for power to allow for portability. After numerous iterations of prototyping Chronoscope's physical enclosure with PLA and ABS to fine tune tolerances, we fabricated the final form from 3D printed resin to create a strong structural integrity and to evoke a weighty, steady feeling when hand-held. We also hand-made silicone covers for the eye piece and the main viewing direction's rotational mechanism to provide a softer, inviting texture when in use.

In parallel, we developed a Python script that securely requests, downloads, processes, and integrates each respective participant's digital photo archive onto Chronoscope. The script essentially creates smaller thumbnails of each digital photo and integrates each with a relational database that is organized and interconnected via the three timeframe modes. We wrote this script to directly interface with either Google Photos or Dropbox. When Chronoscope is turned on, it automatically synchronizes photos with the selected cloud service if there are any new photos. The decision to use these services creates the limitation that participants in our study must have one of these photo storage services and have used it for years. Yet, this decision also provided several important benefits. First, both services are widely used and have existed for over ten years, enabling people to accumulate large photo archives within them, often with little maintenance. Second, these systems generate consistent, easily accessible temporal metadata that are preserved across all digital photos uploaded to them, irrespective of the device or devices that a user may have used to originally take photos (e.g., camera, tablet, smartphone, etc.). Third, these services offer APIs that enabled us to efficiently access and maintain an always up-to-date photo archive on each

participant's respective Chronoscope. This third point is especially important because each time a participant takes photos, they are uploaded to their archive and become present within their Chronoscope as photos accumulate over time, forming interconnections to other photos across the Linear, Date, and Time modalities.

Collectively, these design decisions of Chronoscope features enabled us to (i) generate a quality of change over time, (ii) connect everyday photo taking practices to the temporal qualities of photo viewing through Chronoscope, and (iii) probe on participants' perspectives on the origins of their digital photos, their movement to the cloud, and the subsequent re-materialization through Chronoscope's presence.

5.4.2. Participants, data collection and analysis

We recruited 4 participants from a large city in Western Canada in our study. Similar to the aim of the original technology probes paper [104] and several design-oriented field studies that have followed (e.g., [75,86,90,162,223]), we first focus on a smaller selection of participants to gain a rich, descriptive understanding of the space as a whole to inform future research and practice. We recruited participants through word of mouth and online advertisements. In this paper, we use pseudonyms to describe participants. We selected these participants because, taken together, their respective digital photo archives and photographic practices had showed considerable diversity in terms of size and age:

Table 2: Participant profiles of the Chronoscope project

Participant	**Alice**	**Clara**	**Porter**	**Bell**
Age	mid-30s	late-40s	early-30s	mid-30s
Gender	female	female	male	female
Occupation	hotel/restaurant supervisor	music educator (pianist)	product photographer	grad student in education
Living Environment	apartment with one roommate	shared house with her teen son	house with wife's family	shared house with her partner
Timeframe of Photos	2014-2022	2006-2022	2009-2022	2013-2022
Total Number of Photos	9,921	5,302	2,965	10,932
Cloud Service	Google Photos	Google Photos	Google Photos & Dropbox	Dropbox

We aimed to collect descriptive accounts from participants about their experiences with Chronoscope over time. Each participant had a Chronoscope connected to cloud-based digital photo archive. In the initial interviews, we learned participants' photographic practices and, more generally, their daily lives and practices. Participants gave us a home tour and we set up their respective Chronoscope's connection to Wi-Fi in their preferred domestic location (see Figure 23). We offered a demo of Chronoscope and provided a pamphlet explaining how it works. However, we did not require participants to use or interact with Chronoscope. We explicitly noted that they could develop their own interpretations of Chronoscope based on their interest in using (or not using) it. All were aware they could drop out of the study at any time.

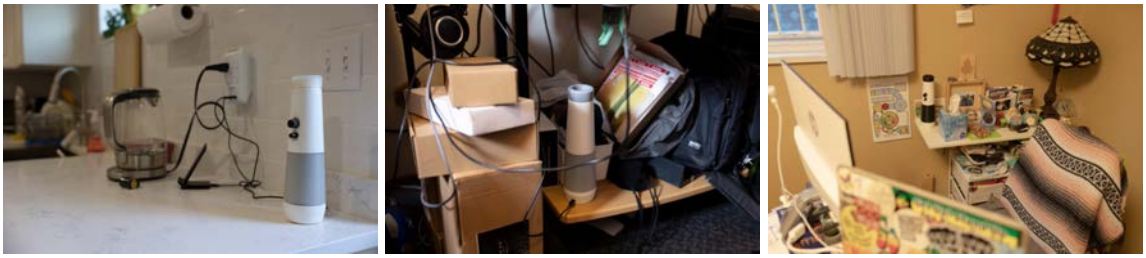


Figure 23: Left to Right: Clara's scope on her kitchen table; Porter's scope under his desk in a shared office; Bell's black scope in her study.

After the initial visit, we conducted bi-weekly interviews over 3 months to check in with participants. We aimed to probe on the degree to which Chronoscope prompted reflective, temporal reminiscence, or other memory-oriented experiences over time. 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 for approximately two hours. Two researchers attended and took field notes in each interview. Fieldnotes were reviewed immediately after each interview, and tentative insights were noted in reflective field memos [78]. We referred to fieldnotes and recordings that captured participants' earlier experiences to explore potential changes in their attitudes toward Chronoscope. 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 mistakes and misinterpretations in them. 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 home visit with our respective participants, we conducted a

preliminary analysis, including a search for themes that stabilizing and shifting patterns across our data that were later drawn out as underlying themes [142]. We coded raw documents with these themes and created affinity diagrams to model connections and differences among participants. Ultimately, this process yielded thirty-one codes and eight themes in total.

5.5. Findings

Next, we present examples taken from field interviews that help best illustrate themes in our findings, with a focus on how Chronoscope mediated experiences of photo viewing related to navigation, reminiscence, and time. To help better contextualize the thematic findings, we begin with a brief overview of our participants' general orientations to their current digital photo archives.

5.5.1. General orientations to digital photo archives

In our initial interviews, all participants communicated highly valuing their digital photos, but also noted key challenges that prevented them from engaging with these archives. These frictions essentially boiled down to two factors: 1) a lack of motivation due to the sheer size of their photo archives and the amount of labor involved, and 2) a lack of awareness around the precise contents of their expansive photo archives. These sentiments are summed up well by **Bell**:

> "I have camera auto-upload because I don't want to lose any of the photos that I take. I always have the intention that one day, we go back and look at them, but that never really happens. Even if I review my photos, I don't go back to 2014. I go to probably last year or something like that just because the sheer amount of photos I have." (**Bell**)

Among four participants, **Clara** exhibited the strongest desire to have control over her archive. She frequently reviewed photos, deleting the unnecessary ones, on her Google Photos account over the past several years with the goal of building a stronger relationship with them through these curatorial actions. However, even a meticulous photo organizer like **Clara** experienced difficulty engaging with her photo archive. She characterized her current interactions with digital photos as largely being attempts at managing them. Yet, the more management controls that were offered, the less in control she felt:

> "I try to control everything, but when I check the photos here [in my archive], I see how powerless I am, especially over time… You can just let it happen, and let it go. You actually have no power to control anything. The only thing we can do is keep is the photos." (**Clara**)

The tensions expressed by our participants stemming from lack of control over and awareness of their personal digital photo archives matches findings from prior HCI research [15,22,170,245]. Collectively, they show that current tools available to them fell short of addressing the sheer scale and size of their respective photo archives and triggered feelings of powerlessness. Yet, all participants were inclined to continue generating and accumulating digital photos in the long-term. Next, we present findings that detail the range of experiences that participants reported having with Chronoscope in and across our field study.

5.5.2. Integrated patterns of use and shifts in attitude over 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 devices they lived with (e.g., [76,87,154,162,223]). Chronoscope extends a considerable amount of control to participants, yet the interaction design is highly open-ended, and the multiple forms of time mobilized to organizing and exploring one's photo archive would take time to understand. While Chronoscope provoked a variety of responses, participants reported integrating Chronoscope into their everyday lives early on in our study. Participants kept Chronoscope in various places, such the bedroom (**Alice**), home office (**Bell**), or shared creative space (**Porter**). After approximately one month in our field study, participants often described a turning point where they came to self-determined understandings of Chronoscope. For **Porter** this turning point was triggered by the perception that Chronoscope instantiated a physical place to collate, connect, and recollect memories bound up in their photo archive. Here, he reflects on the challenges of finding meaningful photos across multiple Cloud services and the role Chronoscope began to play in resurrected a memory-oriented practice that had faded away:

> "I was jumping between Dropbox and Google Photos. …It's hard to find them [as they're] scattered [across] services. Usually, I send the pictures to the friends and family that was involved. After that, I don't usually go back. …It [Chronoscope] reorganized the events and kind of reconstructed those memories. I think it [viewing photos on

> Chronoscope] is more emotionally connected somehow, either with a person or a particular event I remembered." (**Porter**)

Similarly, **Bell** described how the tangible presence of Chronoscope facilitated ongoing interactions that progressively led to new insights emerging around different temporal modalities shaped relations to her photo archive:

> "Because it is a physical thing, it lives here. I see it all the time. …Chronoscope really comes in to help me to be in reflective mindset, so I really appreciate it. It's become part of my habits now. …At the beginning, I didn't really understand what it means to have Date and Time [modes] just because I think we're not used to seeing photos that way. So, they [the modes] helped me to learn different ways of relating to my photos, [and] just think outside the box." (**Bell**)

As **Bell** continued, she discussed how experiences with Chronoscope had begun to shape her photo taking practices. Her reflection illustrates a shift in attitude toward connecting the new photos she takes now with the different points in her past, and how these qualities come together synergistically to create a unique 'footprint' of her sense of self:

> "Last Saturday, I went to celebrate a friend's birthday. When I was taking photos, I feel like later I'm going to be able to relish this memory because of the gadget I have at home from three different vantage points. …I definitely welcome it [Chronoscope] to live with me. I will totally have it in my life because right now a lot of things that we have are dedicated to so many different things. This is dedicated to one thing. It represents a unique footprint of me, and I cherish being able to have access to that." (**Bell**)

Collectively, these examples help illustrate that, despite its open-ended design qualities, Chronoscope became integrated into participants' lives. Its physical presence showed potential to reinforce a sense of ownership over participants' digital photo archives and to reinvigorate prior memory-oriented interactions with digital photos. They also demonstrate Chronoscope could provoke reflections on how one's life history and digital photos can become entangled across over time. Next, we explore this theme more deeply through describing different kinds of memory-oriented photo viewing experiences that participants reported on.

5.5.3. Memory-oriented interactions in and across different temporal modalities

Bell's quote in the prior section touches on the individual and collective capacity for Chronoscope's timeframe modes to provide various temporal 'vantage points' on digital photos and the memories bound up in them. As our study progressed, it became clear that Chronoscope's timeframe modes gave rise to different, yet at times overlapping, ways of remembering, exploring, and interconnecting life experiences. Yet, timeframe modes could also take time to make sense of, at times causing frictions around their intelligibility and intention.

Next, we present examples that best highlight participants' perceptions and attitudes towards various memory-oriented experiences Chronoscope provoked.

Noticing and journeying through changing life stages

Participants often described their experiences using Linear mode—which chronologically organizes their photo archive—as traversing 'waves of time' (**Clara**) where they were able to quickly move across many seasons, birthdays, important events, and so on. For **Bell**, these experiences took on a 'journey-like' quality that provoked her to develop a narrative for interpreting the trajectory of life experiences she encountered and navigated across:

> "When I was going through the Linear mode, I actually feel the *journey* of my life. I'm reminded that there's a big picture there. I feel all kinds of emotions. I feel really grateful and very fortunate to be able to experience all the things that I have experienced, but also being able to experience that again, when I was going forward in time [with Chronoscope]." (**Bell**)

Bell's reflection exemplifies instances where participants reported gaining an extended awareness of the scale of memories captured in their photo archives. Participants also reported on experiences that focused in on key episodes in their respective life stories which often marked a progression through life stages that came with shifting priorities:

> "I can see my life path through this Linear mode. I realized in my early 20s, I'm always traveling, going to different countries, doing different kinds of things outdoor with my friends or my family. But after certain years, my photos become much less than before. …which means I [am] getting busier and have less time [for travel]." (**Alice**)

Clara noted that while the rate at which she took photos remained constant, she noticed a distinct shift in 'what is important' in her life over time. As an accomplished pianist, she reflected her shifting orientation toward piano playing prior to and after her son was born:

> "I'm not focusing on myself anymore. It just happened naturally as time goes by. You focus on yourself. You want to make yourself better. But then gradually, you stand out to look at the world and want to look for many other things, instead of just for yourself. …I came across one picture of my recital many years ago, and I don't do recital anymore now. But l still play piano. I still teach. …I still do very similar things, but you know, it's totally different now — I have a different purpose …seeing that change through my photos showed I present myself differently now." (**Clara**)

These examples illustrate how participants leveraged Chronoscope to examine traces of their past self and to move across different life stages. This, in turn, could lead to a broader overall awareness of scale of memories within the archive as well as meditations on one's history in relation to the current lived present. Next, we dig deeper how non-chronological timeframe modes mediated participants' photo interactions and remembering practices.

Serially exploring annual events, forgotten mundane moments, and contemplating future actions

Participants used Date mode to explore significant episodic life events. Yet the capacity to explore these events relationally, in series, across years supported alternative ways of navigating and remembering momentous past experiences. **Porter's** reflection is exemplary of this theme:

> "It's like I'm going to each event individually in the Date mode but across time. They [photos in archive] are sorted continuously, so I can have a sense of almost like a flashback to each event and how they're woven together. …Labor room in hospital, birth of baby, …lots of birthday celebration pictures and baby pictures on October 29th, which is my son's and wife's birthday. Viewing them in Date mode, I felt a sense of happiness and joy of becoming a father. …As I went through the pictures this way, it showed me so many good memories from back in Asia, during [different] Chinese New Years all together. It makes me want to make more meaningful memories with loved ones." (**Porter**)

In contrast to focusing on significant annual events (e.g., birthdays, holidays, etc.), **Bell** leveraged Date mode to explore the many mundane, yet valued moments between them:

> "I don't take myself as someone who does a lot of selfies. When I used it [Chronoscope in Date mode], I was like… oh, there's a selfie. Oh, there's another one. And a lot of it is just random [shots] of me and my partner. …It really reminds me of the mundane, joyful moments. It's those moments that we tend to forget, we tend to remember the bigger memories, the more memorable ones. But I think that it is those like tiny ones that are very worth "tasting". In Chinese, we will say 'hui wei', [which means] we can go back and taste the nice little surprise. And I'll show it to my partner: You remember we took that photo? What were we doing?" (**Bell**)

Interestingly, **Alice** also described using Date mode as a resource to probe into what she had recorded about her life on particular dates in the past to get inspiration for planning dinners, parties, and surprises for friends in the near future:

> "When I want to plan an event for a specific day, I definitely will use the Date mode to check what I've done in the past. …There are some special days that I really like to celebrate every year. For example, my birthday, Thanksgiving, Christmas and Chinese New Year …I don't like to always do the same things for same days. So date mode helps me to avoid doing the same things and get some new ideas." (**Alice**)

However, tensions did arise when people tried to search for specific dates that were meaningful but in a different calendar system. **Bell** shared that:

> "I realized I couldn't [find] Lunar New Year because [it] uses [the] lunar calendar. It's actually different days every year, so it's cool to reflect on the difference in seeing time. But still, I just went to that general day frame lunar year usually happens. And I think because I couldn't really celebrate lunar new year [this year due to COVID-19]… I think being able to go back and see how I celebrated it, and seeing a whole chunk [of photos] in there all at the same time, was very comforting." (**Bell**)

Collectively, these examples illustrate how participants explored past life experience —both momentous and mundane, if not totally forgotten— as they serially cut across calendrical time with Date mode. They also exhibit considerable diversity from **Porter**'s contemplation of momentous life events viewed in series, to **Bell**'s approach to enacting 'hui wei' to encounter surprises 'in between' dates that are traditionally regarded as important, and to **Alice**'s practice of viewing records of her actions of past dates to inform her future actions.

Discovering everyday patterns, element of surprise, and seeking change with Time Mode

Time mode, which organizes all photos based on the time of day they were taken irrespective of the date, required the most amount of time for participants to understand. Initially, **Clara**, **Porter**, and **Bell** experienced challenges in interpreting this kind of non-chronological temporal modality. For the majority of participants, these frictions eventually faded as our study progressed and often new insights were revealed about their actions tied to different periods in the day. **Clara** describes how her perception shifted from viewing Time mode initially as 'random' to noticing distinct moments of growth in her piano teaching practice as well as similarities in her routine that spanned over a decade:

> "For me, at first it was more like, checking pictures randomly. Actually, no order! When I'd try to find some photos, it was hard to do it in this way. It was more like a game of guessing. …But then I found when I teach [piano lessons], I sometimes take photos to show my students. Look at your hand shape! …those photos showed how they moved and improved. …in this way, [Time mode] is more dynamic, it shows pattern and real routine. …In Linear or Date mode, we find the time waves, right? But for here [in Time mode], it's like you're jumping but you still see similar things. And it's a short routine in your one day, every day or every afternoon. …Even in ten years, I found there are parts of the day I'm doing the same thing! [laughs]." (**Clara**)

In other cases, the somewhat unpredictable quality evoked through exploring photos in a cyclical way bound within a 24-hour frame could create an 'element of surprise' and lead to experiences of anticipation over time. Here, **Bell** reflects on discovering an array of largely forgotten morning-time activities she engaged in over the past decade which helped motivate her to be more resilient when facing an artistic rut:

> "The *element of surprise* is always there [in Time mode]. …Finding out that I've actually done a lot in the morning was very encouraging. And I didn't just waste my morning time all this time. Once upon a time, I did stuff! It brings up a lot of emotions, a lot of feeling grateful, feeling like… okay, let's keep going. I feel encouraged. I feel motivated by my past self. I'm not alone. I really appreciate being able to find patterns across my days. I had all these good feelings because I am able to experience my journey through this unique slice of time I didn't expect." (**Bell**)

While unfamiliar at first, Time mode opened new interactions for participants as they explored different conceptualizations of time (e.g., work time, leisure time, social time) across their collective photo archive. This could, in effect, lead to experiences of

anticipation, self-affirmation, and new insights into everyday patterns and routines in ways that cut across over a decade of photos. Next, we explore participants' experiences between and across different timeframe modes and the role this interconnectedness played in shaping their memory-oriented engagements with their respective digital photo archives.

5.5.4. Cumulative experiences with Chronoscope: modulating pacing, exploring interconnections, and speculating longer-term relations

In addition to offering different temporal modalities to organize and interact with one's digital photo archive, Chronoscope enabled participants to modulate the relative pacing that they moved through their photos across time. In prior work, Chen et al. [31] speculated that integrating control over this quality of interaction (termed 'temporal granularity') could help prevent users from getting 'stuck-in-time' – a tension surfacing when a photo archive's density is so great that it would be considerably challenging to move to another time period (e.g., where they may be thousands of photos that would require thousands of rotations or presses of a button). In our field study, we found all participants made use of the temporal granularity knob to modulate their movement through time surrounding different life episodes, life events, and mundane periods in their respective archives. **Bell's** reflection is exemplary in how it captures frictions emerging from getting stuck-in-time and inventive workarounds that participants developed to alleviate these tensions:

> "I turned on [my Chronoscope] and wanted to explore around 2:15 [in Time mode]. But the first photo was at 10 o'clock. I was like, Oh, 10 o'clock, that's a few hours from 2:15. Cool. Two minutes later [after rotating Chronoscope continuously], it's at 10:01. I took many photos at 10:02! It's taking forever to get there. …I was sitting in my office and my partner asked me: *what are you doing?* I'm trying to get to two o'clock right now! I figured out I could change it to Linear mode, find a photo around two o'clock and change it back to Time mode. …Now, I usually have it [granularity] to the largest, which is 10 because it gives me kind of quick view, a broad brush across time. And then if I see something in there that I want to focus on, then I make [the granularity] smaller so I can go back and focus on that time [period] in my past." (**Bell**)

Clara described the value of being able to oscillate between the slowest and fastest interaction pacing with the granularity knob, noting the different, often contrasting, forms of memory-oriented experiences they could surface:

> "Yeah, about slow and fast. I like how [with] slow, I can find a thing, a time in my life, and look in at it. With fast, I like how I can compare experiences, you know, move back and forth quickly over 10 years. I can see a huge part of my history in a short time." (**Clara**)

As our dialogue continued, **Clara** remarked on how using the various interaction modalities of Chronoscope came together as a synthetic experience to shift her perspective on the potentialities of interacting with digital photo archive – a shift toward new forms of *engagement with* as opposed to *management of* photos. This, in turn, led to a greater sense of *agency* over her digital photo archive and a desire to potentially expand her everyday photo taking practice:

> "In my own experience of using Chronoscope, [it] offers agency. It gives new opportunities to reflect on those memories [in photo archive], not just managing and deleting something new. …Chronoscope connects everything [in my photo archive] together. It strings together a context of connections for people to orient and move around from these different perspectives in time." (**Clara**)

In our final interviews, participants also discussed and reflected on the temporally interconnective qualities of Chronoscope which bound each photo to three separate points in time in the photo archive. These instances were often characterized by unexpected, yet profound experiences of bringing together multiple threads in time in a participant's life history in a synthetic, immediate way. **Porter** described landing on photo of his wedding, only to find another photo of his parents immediately in the periphery (while using Date mode). The juxtaposition across time of these two distinct memories was seen as highly significant:

> "It has been a long time since I saw my parents together. We're a satellite family[4]. My Dad visited twice in 10 years. …The picture [in the periphery] was taken by phone in 2016 before my wedding in [large Canadian city depicted in the main image]. This picture was before a milestone in life (getting married) and it reflects on how much my dad has sacrificed the family time to provide for us overseas. These pictures together mean to me that I want to be there for my kids and try to make

[4] A 'satellite family' is a form of distributed family organization where the primary income earner does not live in the same geographic place where most family members are located at.

> it work, but also that I have fond childhood memories when [my parents'] whole family was living together." (**Porter**)

The qualities of personal history, interconnection, and life transitions captured in **Porter's** experience with Chronoscope also emerged in other interviews. **Clara** describes an intriguing interconnection formed by Chronoscope (here, in the Time mode) where she metaphorically and practically saw herself moving off stage through a photo of her on stage as a music performer being connected in sequence with her more contemporary role as a music instructor:

> "Everyone has some glorious moments in life. But it's so different now and [that comes out] when looking back photos from different times in life. I mean, for example, the photos of the recitals. When you stand on the stage, and it feels so proud, or nervous, or happy. But when you check the picture now, it's a totally different feeling considering the other photos surrounding it. You see what you do now in life and what you did years ago. Now, what I see [in the older recital photo] is everything behind that stage scene, like how much time I devoted, how much time I spent in the practice room, and how I picked that dress." (**Clara**)

Porter described how the temporal qualities of Chronoscope created enough context for loved ones, beyond their own life, to potentially make sense of their photo archive and intelligibly engage with it:

> "If I give my photo archive to the next generation, I wouldn't just throw [in] everything and give it to them. I know if I'm handing down my Chronoscope, [the timeframe modes are] something that's connecting me and my photos in a way that a person can understand." (**Porter**)

For **Bell**, the passing down idea reminded her of the importance of having intimate family conversation and of knowing what has actually happened in both familial and societal histories.

> "[My time with Chronoscope has made me] imagine a scenario where, because photos are documented digitally [and temporally] organized, instead of going hours and hours with the fixed physical photos, you will have something that captures someone's life through time, and then be able to find [and] historicize times in their life. …When I was a kid, my grandpa told me tons of stories about him being in the Civil War... before Taiwan became Taiwan, when he was still in China. And as a kid, I didn't appreciate that at all. I wish I actually cherished those moments. But if he had something like it [Chronoscope] that he could've handed off to me, I would give anything for it. …All of these [photos] are all clued into the historical moment that we live in. Even though you're looking at someone's personal photos, the time [frame] modes give you just an

> idea of what's happening at the time from this person's positionality and identity, and how they experienced time. And this has great potential for us to be able to tap into things that can change, like the way personal history does." (**Bell**)

Alice contemplated the longer-term viability of her photo archive operating as a resource for reminiscing on the trajectory of her life history at a point in the future when she is older:

> "When I'm getting older like 50 or 60, I [would] want to go check my youth time more, like what I've done before. It will be more meaningful. I think it [Chronoscope] might work better for people over a certain age, like in their elderly life. I think they will be super happy. But to most young people, they just live at the moment. Their life is too busy to do that kind of romantic thing." (**Alice**)

Collectively, these examples show that participants' experiences with Chronoscope remained valuable over time and illustrate how various temporal modalities generated an evolving quality of interconnection across the memories and associations that make up their life history. These qualities could together to evoke a quality that had a longer-term tail within participants' lives and potentially extending beyond them. Yet, **Alice** makes a salient point—there is a time and place in one's life for reminiscing with digital photos and such interactions may not scale to all generations.

5.6. Discussion and implications

Accessing and interacting with digital photos are essential factors shaping how people locate, retrieve, recollect and share memories. Yet, prior research (e.g., [15,22,170,245]) and our findings suggest that current technology often complicates and limits these practices. Our work offers key contributions that advance current research in the following ways:

- Using temporal metadata as a memory cue to create and trigger journey-based exploration in one's life history;
- Providing ways to support people's exploration of potentially forgotten or unknown life patterns over time;
- Extending the conceptual lens of slow technology through developing more diversified strategies to design with temporality.

Next, we discuss opportunities and challenges tied to these points.

5.6.1. Creating journey-based interaction design for memory-oriented photo viewing experiences

Prior research has investigated how revisitation of one or a small subset of photos brought reflective value to people's everyday lives (e.g., [162,223]). Targeting people's relationship with their entire photo archive, our approach extends control over three temporal modalities to navigate unique pathways through multiple memories and life stages. These pathways opened new ways of mediating interactions with digital photos which participants characterized as 'journeys' across their life experiences, such as **Porter's** contemplation of family life after a photo of his wedding was juxtaposed to one of his parents. From here, we see that by providing a particular context of cuing through situating each photo in time relationally with others, participants were able to creatively explore and construct their autobiographical memories with an increased awareness of potential correlations between different life events. According to our findings, people valued this form of journey-based photo interaction when it resurfaced forgotten or unknown life patterns, especially those in less familiar modes, such as *Date* and *Time*. Because it is not easy to anticipate what photos would be interconnected in those two modes, people can revisit, associate, and reflect on multiple surprising moments at once in their exploration journey, triggering a provocative way of integrating and interpreting autobiographical memories [16,17,99]. Through our study of Chronoscope, we offer a design case of using temporal metadata as a memory cue to trigger a journey-based remembering process that brings more curiosity, anticipation, and reflection into play. However, one limitation of using temporal metadata as a memory cue is that the timestamp data are finite and relatively inflexible, which may lead to potential issues in relation to integrating photos taken in different time zones and calendar systems.

Prior research has also indicated that mundane events in autobiographical memories that were repeated, continued into the present, or had an accumulative influence on one's life could be an important but often overlooked design consideration [143]. Echoing this point, **Bell**'s enacting of 'hui wei' to rediscover (or 'taste') mundane, largely forgotten moments with her partner shows opportunities for future design research efforts to leverage concepts of temporal interconnectedness and temporal modalities to further investigate the potential value of re-encountering such mundane moments. While temporal attributes from standardized timestamps encoded within

photos are limited (e.g., time of day, date, and timezone), our research has shown they can be effective at providing enough context for people to locate and revisit life patterns, rhythms and cycles while equally leaving space for interpretative, spontaneous, or serendipitous encounters over time. Our study offers early evidence validating the potential of this approach. Yet, clearly there is an opportunity for future research to make use of such temporal attributes to better understand the range of emotional valences and associations that people may experience when navigating across their life patterns and experiences in their digital photo archives.

Our findings also reveal that more built-in support is needed to engage journey-based photo interaction. According to Axtell et al. [5], 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 past memories or for spontaneous reminiscence. A key dimension of the Chronoscope design is using *juxtaposition* as a visual technique to generate a sense of peripheral awareness of neighboring photos in the sequence relative to the photo-in-view. This feature is paired with a granularity control to fast forward memories easily. Our findings revealed this subtle technique enabled people to better contextualize each photo's location in time in a relational way, as described by **Clara** that Chronoscope "strings together a context of connections" and offers *agency* for photo engagement. However, our design does not offer a way for people to curate or share their photo history. Instead of showcasing a selection of photos as album-based management tools would often do, we see opportunities in providing ways for people to retrace mundane or momentous trajectories to revisit them or to share them with others. In our study, **Alice** and **Bell** both suggested a need to explore photos collaboratively with others, even if from their own personal archive. This suggests an opportunity for future research to investigate how temporal trajectories might be dynamically preserved and revisited as they accumulate over time. Such interactions could give rise to memory-oriented experiences that offer unique comparisons and entanglements of life histories among a group and potentially catalyze collocated social interactions. Future research in this direction making use of temporal modalities can extend prior work on collocated photo-mediated reminiscence which has largely relied on randomness or sequential exploration (e.g., [95,162,223]), while also contributing to recent calls for alternative design strategies for collocated remembering [21].

5.6.2. Supporting longer-term relations with malleable forms of time

Chronoscope's dynamic temporal qualities generated possibilities for participants' relations with it to change over time. It continually updated its archive to represent the entirety of their photo archive each time it was encountered, which connected the present moment to the past. This ongoing quality of change led to a continual reorganization of the archive as each new photo introduced into it was interconnected to other different photos in and across time. These qualities also came together as a synthetic experience for participants that led to increased ownership and agency over their photo archives. This, in turn, led to a renewed interest in their photo archives as they became embodied, changing digital resources to be materialized through Chronoscope in participants' everyday lives. Participants valued the capacity for new photos to be, as **Porter** described, 'stitched' into varied expressions of time in their personal history simultaneously. This led to interconnections forming among memories, experiences, and life stages in both chronological and non-chronological ways, such as **Clara's** reflection on her transition off stage from musical performer to instructor as she noticed sequences of photos capturing the progression in form of her students' hands playing the piano over the years. We found that this design quality came full circle by mediating participant's own photo taking practices, such as in **Bell's** anticipation of where the social gathering photos may end up when interconnected among three different temporal 'vantage points' in the moment she was taking them. Findings also showed that participants valued this ongoing, integrative, and accumulative quality. It is what prompted prospective reflections on the potential longer-term place that Chronoscope could occupy in their own lives and potentially scaling beyond it to future generations.

Collectively, these findings support the vision of slow technology, while offering new insights for temporal technologies that can be investigated in future research. They show that opening a space to explore how a person's life history is bound up in their photo archive with different temporal modalities offers pathways uniquely reflective of the use, that take time to interpret, and that change over time in an ongoing way into the future. Our research contributes a case that builds on and advances ongoing work in HCI that investigated how technologies can find a longer-term place in people's everyday lives and co-evolve alongside them (e.g., [7,159,167,169,180,240]). Additionally, due to digital photo archives being immaterial, massive in scale, and

proliferated across potentially wide timeframes, we built in support for modulating the pace of movement through time with the temporal granularity control. Participants productively made use of this added degree of control for manipulating their pathways through time – from traversing through many memories across the years to slowing down for conscious contemplation on a specific moment in time. Following Rapp's work [184], these findings validate their recently proposed opportunities designing in control over the velocity of movement through time and enabling users to gain a grasp on more malleable representations of time. Yet, research has also shown that temporal media (e.g., audio or music [169]) and other forms of personal data outside of digital photos will likely require different techniques. More research is needed to investigate design strategies for manifesting the movement, velocity, and malleability of time through personal data; and, following Alice's skepticism over the generational viability, at what touchpoints in one's life such memory-oriented temporal technologies would be of value.

5.6.3. Mobilizing and extending diverse temporalities across diferent forms of personal data

Enabling participants to move across different forms of time with the timeframe knob and at different speeds with the granularity control, all while remaining anchored in time by the temporal metadata of the specific photo-in-view supported a range of reflective experiences. Our research validates the proposal from prior work [7,15,114] that situating mobilizing a *Linear* timeline-like chronological timeframe mode provided a useful contextual point of reference for participants to navigate their photos. It also builds on recent research [169] by demonstrating that the integration of this chronological modality can be productively scaffolded by participants to interpret and progressively understand the more unusual non-chronological modalities of *Date* and *Time*. Yet, we also found there are limits to this approach. **Bell**'s struggle to locate distinct photo sequences of Lunar New Year experiences across the years in Date mode emerged due to a misalignment between the Lunar calendar with the Western calendrical system that our temporal metadata uses. Additionally, another limitation that emerged through studying Chronoscope is that it connects photos in a sequence that entirely hides the 'temporal blanks' or gaps in periods when one did not take any photos in their life. Temporal blanks in one's photo archive may hold important meaning in one's life history, such as intentional removal of memories, less interesting life patterns, or fluctuating patterns of when one was awake and active. There is an opportunity for future work to

explore how temporal blanks existing in photo archives might be better acknowledged and leveraged as a creative design resource in photo viewing applications. Collectively, these tensions highlight the critical need for future research to explore the design of new systems that mobilize and express more diverse forms of time as temporal modalities. New design initiatives can build on growing research in HCI that actively investigates the social (e.g., [20,138]), cultural (e.g., [217]), political (e.g., [3,179,181]), and ecological (e.g., [49,183]) dimensions of time. While there exists a trajectory of HCI research exploring the combination of digital media with different input and output modalities (e.g., [66,114,152,153]), there remains surprisingly little work that has considered what role diverse forms of temporal modalities might play in opening new perspectives on and interactions with personal historical data.

5.7. Conclusion

We studied Chronoscope to explore personal history as an element of temporality raised by slow technology, and to investigate how this framing might offer a generative lens of supporting memory-oriented interactions with personal digital photo archives. Through building and deploying a small batch of Chronoscope research products we were able to gain insights into people's real and situated experiences of their digital photos through a novel temporal lens as well as how their perceptions of both the device and their photo archive shifted over time. Our findings provide new insights into how mobilizing interconnected temporal modalities can offer unique ways of interacting with digital photo archives in ways that overcame limitations commonly experiences with contemporary photo viewing applications that inhibit remembering experiences. They also detail how physical form, 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. Our research also contributes to calls in the HCI community that call for longer-term programs of design research [186]. Ultimately, we hope this research future work inquiring into the role, place, and pace of digital data in everyday life, over time and into the future.

Chapter 6.

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

6.1. Overview

Based on the findings in our deployment study of Chronoscope, we discovered design opportunities in relation to interaction pacing, user control, and timing. We first discovered an interesting notion called *temporal blanks*. Chronoscope has one limitation in that it connects photos in a sequence that entirely hides the 'blanks' or 'gaps' in periods when one did not take any photos in their life. Our research team considered that this kind of temporal blanks in one's photo archive may hold important meaning in one's life history, such as intentional removal of key life experience (e.g., due to a romantic breakup, loss of a loved one etc.). Second, we became interested in providing fewer user controls for people to engage with their entire digital photo archives. Chronoscope provides multiple sophisticated user controls (viewing directions, timeframe modes, and temporal granularity). While these controls supported participants to flexibly explore their photos in and across time, they took time for people to fully understand how it works and made the photo viewing process quite proactive and intentional. Thus, both the notion of temporal blanks and the design of user controls prompted me to think: How do people perceive temporal blanks in their digital photo history? How does user control affect the ways people reflect on their photos? And ultimately, what does it mean for one to view their digital photo archives as a whole?

To brainstorm ideas for the next digital photo wayfaring project, I engaged in a critical, reflexive, and iterative design process similar to how I arrived at Chronoscope. Through iteratively generating design ideas and critically assessing them by potential research questions about time and slow technology, I progressively narrowed the ideas down to a core concept in relation to the perpetual movement of time. This core concept applies the current clock time to constantly tie the present moment to one's past. This constant connection between the past and the present is designed with an aim to create a sense of ongoingness and intimacy between one and their past selves. Motivated by

this concept and how it could affect people's lived experiences with their digital photos, I proposed my fourth research question:

RQ4: What opportunities exist to leverage 'current clock time' as a design resource that supports new ways of experiencing the trajectory of digital photos one has accumulated in their life?

To investigate this question, I created the second main design case in my dissertation research called PhotoClock, a mobile application that leverages the creation date and time embedded in digital photos to encourage contemplation of memories from the past bound up in one's photo archive. A key objective in the PhotoClock project is to explore how the perpetual movement of time can be leveraged as a unique resource to continually connect the present moment to people's photos taken around that same time of the day in the past. In particular, I aim to investigate how people perceive their memories through digital photos displayed ephemerally only around the clock time they were taken in the past[5]. Through eight months of iteration in our RtD process, we arrived at the final version of PhotoClock, a design exemplar of leveraging the perpetual movement of time to enrich memory-oriented experiences.

Our research team recruited 12 participants to live with and experience this PhotoClock research product over an eight-week period through a field deployment study. Next, I will unpack the details into this design and deployment study.

[5] This chapter is adapted from a publication in DIS'23: Amy Yo Sue Chen, William Odom, Carman Neustaedter, and Sol Kang. (2023, accepted). PhotoClock: Reliving Memories in Digital Photos as the Clock Ticks in the Present Moment. Submitted to Designing Interactive Systems 2023 Conference, ACM, Pittsburgh, Pennsylvania, USA.

Figure 24: 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.

6.2. 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 [38]. 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 [24].

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 [161,170,215]. This tension can create barriers for people to gauge how big their archive is and, consequently, revisit experiences, histories, and impressions captured within them [170,245]. 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 [15]. 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., [31,54,95,162,223]). 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" [136:11]. 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* [85,163] 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 24). 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 25). 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.

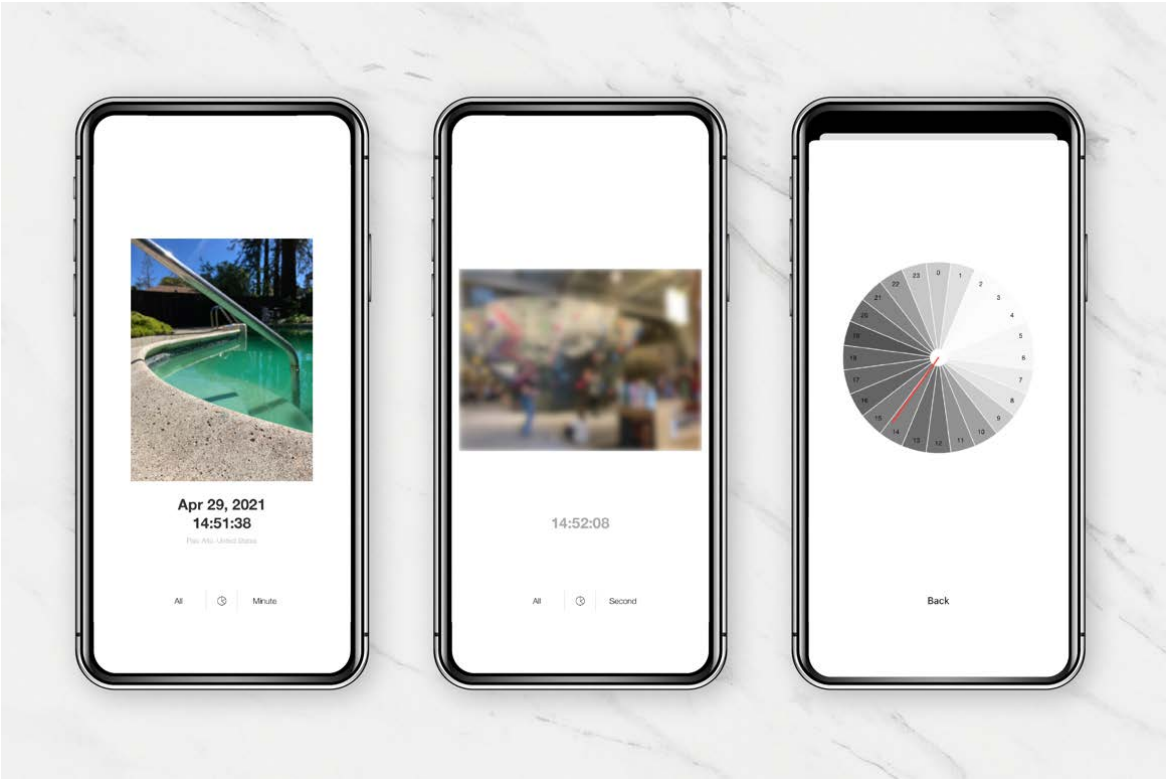


Figure 25: The user interface of PhotoClock.
Left: The user sees a photo clearly with all the metadata presented in the page. ***Middle***: In a special case, the user sees a blurry photo and it gets clearer as time goes by. ***Right*****:** The user enters the Sunburst page and see how many photos were taken in this device throughout the 24 hours. The darker the color is, the more photos were taken within that particular hour.

We created a highly robust research product [168] 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.

6.3. Literature review

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

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 [170], but this quality also makes it difficult for people to grasp how vast and fragmented their photo archives are [245]. 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., [22,115]). This phenomenon may result from the difficulty in deciding which photos they want to preserve, revisit, or forget [146]. Researchers have shown that tensions associated with such decisions can become further amplified when it comes to romantic breakups [92,93,197] and the death of loved ones [165,198].

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 [160,223], identity construction [40,41,89], and self-growth [39,131]. 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 [22,245]. According to Bergman et al. [15], 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 [5], slideshows [2,5], keyword searching, and face recognition do help, but

more diverse and alternative design approaches are critically needed [15]. Beyond an individual focus, digital photos also operate as important resources for collective remembering and intimate communication among loved ones [4,91,209] and family members [43,51,128,229,230,245]. 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.

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 [36,56,82,170,189] and life histories [35,55,98] in ways that are open to ongoing interpretation [195]. 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*" [57:48]. 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" [170:991]. 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." [82:3460]. 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 [57,170]. For example, music players such as Olly [167], Olo Radio [169], and Musée [107] use user's music listening history to resurface songs people once felt strongly connected to at a certain point in their past. Chronoscope [31] 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 [114] 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.

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" [85:203] and that emphasize the "presence – not absence – of time." [85:204] 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 [70] applied a slow technology framework to catalyze imaginative experiences through an augmented reality museum installation. Grosse-Hering et al.'s Slow Juicer [80] and Pschetz and Banks' Long Living Chair [180] 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 [223], Photobox [162], Olly [167], Postulator [87] and Family Stories [94] 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 [126,163,179,181,222]. In this context, researchers have turned to embrace alternative conceptualizations of time. Several works, such as rhythms of pause [64], crescendo expression [222], and culturally relative notions of time [217], have articulated the importance of temporal structures in the design of interactive experiences. Pschetz and colleagues [20,181,185] 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 [184] 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.

6.4. Methodology

Our design research process was influenced by the concept of *research products* [28,157,168]—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., [169]), 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.

6.4.1. 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 [84,136,163]. 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 [163]. 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" [163:174]. *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" [163:174]. 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" [163:174].

Nascent design research exploring slow messaging systems, such as *Future Me* [154,173], *Slowly* [250], and *CrescendoMessage* [222], 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*" [130:1641]. 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.

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 will fade in and start displaying photos according to the clock time (See Figure 26).

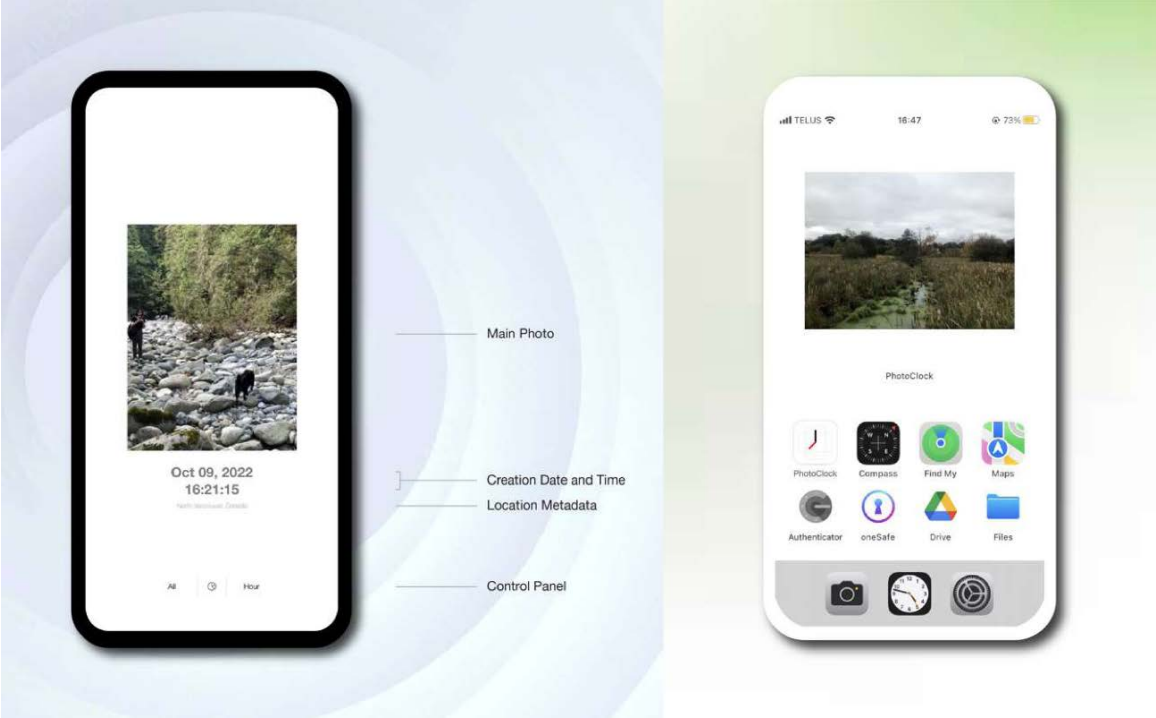


Figure 26: How PhotoClock presents itself and the metadata of photos
Left: Using the current clock time, the PhotoClock app finds a photo taken around the same time of day in the past and presents it alongside with the temporal and location metadata to its user. The Control Panel displays the current 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.

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 [169]. 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 27). 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.

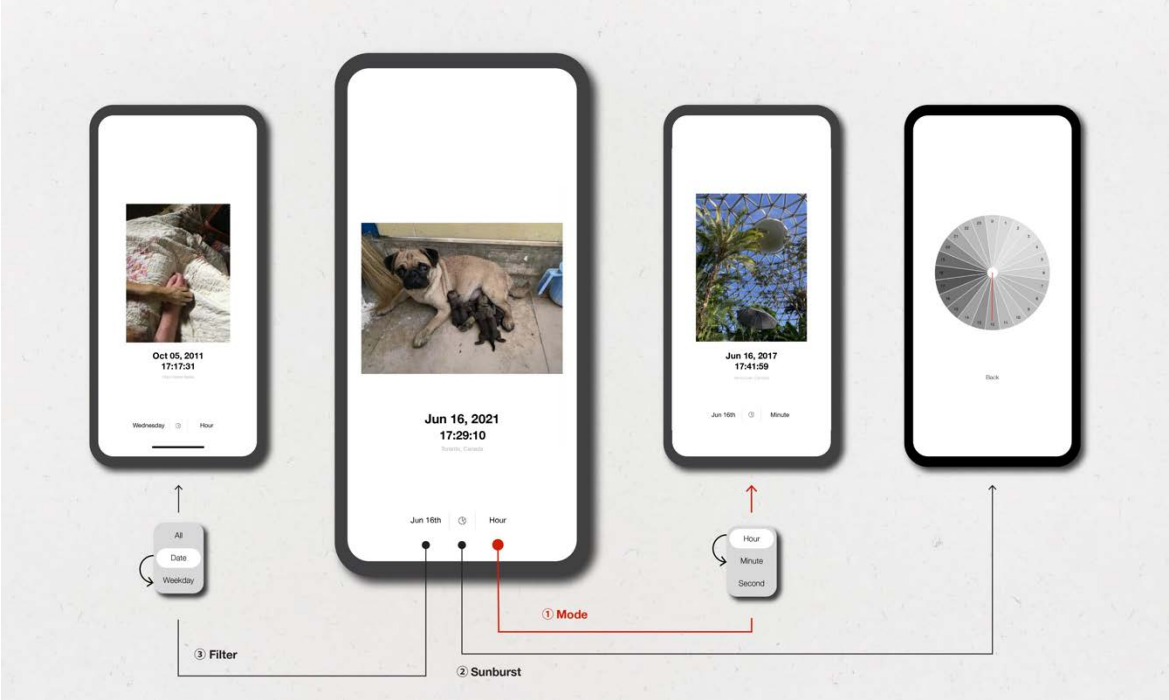


Figure 27: Three buttons in the Control Panel
① The main button on the right toggles between the three pacing modes (Hour, Minute, and Second). ② The middle one with a pie chart icon on it stands as an entry to the Sunburst page. ③ The left one allows its user to toggle between the three selection filters (All, Date, and Weekday).

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 [33]; 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. [189] argue that people do not follow a set path to their imagined 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 [222] 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 28).

Figure 28: 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.

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 [136,163], 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.

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 [251], 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 29.

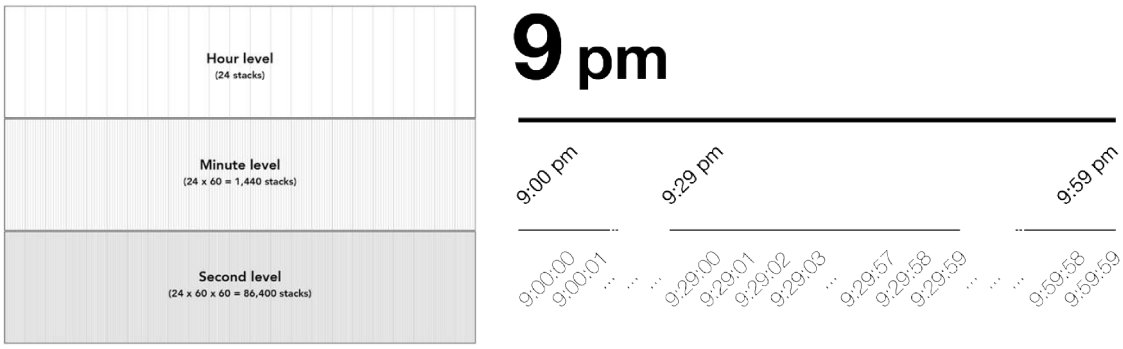


Figure 29: Stacks hierarchy of PhotoClock.
Photos taken within a specific time period will be put into the same stack. The system selects a stack based on the current clock time, and randomly picks one photo from the designated stack to show its user. Every photo identifier is stored in a specific second 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.

6.4.2. Field deployment study: participants, data collection and analysis

We recruited 12 participants from North America through word of mouth and snowball sampling methods (see Table 3).

Table 3: Participant profiles of the PhotoClock project

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

Similar to the aim of the original technology probes paper [104], 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.

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. 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 [78]. 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 [142]. We coded raw documents with these themes and created affinity diagrams to model connections and differences among participants. Ultimately, this process yielded five main themes, such as *general usage*, *ephemerality and dynamics*, *reflection on the passage of time*, *life patterns and memories*, and *longevity and cumulative experience*.

Figure 30: Participants provided pictures of how they use PhotoClock.
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.

6.5. 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 [15,22,115,170,245]. 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.

6.5.1. 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., [76,87,154,223]). 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.

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.

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.

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.

6.5.2. 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.

6.5.3. 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 [57,189], 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.

6.6. Discussion and implications

Interacting with digital photos shapes how people locate, retrieve, recollect, and share memories. Our findings validate and extend prior work ([15,22,170,245]) 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.

6.6.1. 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 [16,17,99]. 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” [100:110]. 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) [61,123,242], 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 [114]), 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., [91] and **Keith**'s emerging accumulation of video memories).

6.6.2. 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 [5,21], 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. [5], 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).

6.6.3. 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 [196,204], 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* [57,189] 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., [64]) 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.

6.7. 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.

Chapter 7.

Extending a Theory of Slow Technology for Design through Artifact Analysis

7.1. Overview

Findings from the previous chapter show that PhotoClock's minimal controls created a flow-based photo viewing experience that supports participants to rediscover their trajectory of life journeys in a way where memories could be ephemeral. 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'. 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 participants, the PhotoClock interaction design resembles the way they usually recalled memories—through unintentional, incidental, or serendipitous moments as opposed to proactive search. 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.

In parallel to the PhotoClock project, my supervisor, an additional academic collaborator, and I collectively saw an opportunity to conduct an artifact analysis of a collection of slow technology design examples in order to extend a theory of slow technology. Artifact analysis is a method that performs analysis on a small set of design artifacts as a way to assess the stability of existing design theories. Artifact analysis can also support a discussion or an update of design qualities and reveal opportunities for developing new theoretical concepts. With an aim to assess the theory of slow technology, we included Chronoscope and other design cases in our artifact analysis. The research question that guided our analysis is:

RQ5: What opportunities exist to extend a theory of slow technology for interaction design through more diverse and expressive design qualities in relation to time?

My primary aim here is to investigate the intersection of slow technology, temporality, and digital photos. My secondary goal is to contribute more broadly to the development and extension of the original slow technology vision and enable the theory to be more robust and practically accessible to design practitioners and researchers. We reported the results of our artifact analysis to illustrate how slow technologies could be designed to invite reflection in a recently published journal article:

The theory of slow technology was originally outlined by Hallnäs & Redström in 2001 where its vision was articulated through three core concepts: *reflective technology*, *time technology*, and *amplified environments* [85]. In our journal article, we developed and refined eight design qualities through detailed artifact analysis of seven design artifacts that exemplify key aspects of the extended theory. Two of these design artifacts, Chronoscope and Crescendo Message, resulted directly from projects I have led.

As an extension to the journal article, I conducted an additional artifact analysis on PhotoClock in Section 7.7.8 and detail new theoretical insights that it reveals in light of our prior research in the Section 7.6.9 (Synchronicity) and the end of Section 7.8 (Revisiting the theory). These sections further contribute to our prior research of extending the slow technology theory. Next, I unpack the details of our theoretical reflection on slow technology and the artifact analysis that extends our understanding of this impactful design strategy in the HCI design field.

7.2. Introduction

People's daily experiences and the environments they inhabit have become saturated with digital devices and systems. With this shift, new concerns have emerged across the HCI community over the role, place, and pace of new technologies, and how they mediate people's experiences in their everyday lives. Hallnäs and Redström's foundational article on slow technology argues that the increasing availability of technology outside of the workplace requires designers to expand their focus beyond creating tools to make people's lives more efficient to "*creating technology that surrounds us and therefore is part of our lives over long periods of time*" [85:201]. They call for new design initiatives that amplify and stretch *time presence* in everyday life, and reveal an expression of present time that is slower. Hallnäs and Redström outline a design research agenda aimed at challenging values of optimized performance and creating technologies that support moments of self-reflection as well as critical reflection on technology itself, known as "slow technology."

The slow technology design philosophy offers a critical and generative vision to frame investigations into how longer-term human-technology relations could be supported with computational objects. Lately, the HCI community has seen a resurgence of interest in this area. Tensions have also surfaced. The proposal of slow technology is visionary, yet also abstract. Several international workshops have revealed that designers and researchers have struggled to put conceptual ideas of slowness into practice [127,156,159]. Tensions have emerged from a lack of guidance in designing technologies that present slower temporal expressions and are capable of sustaining longer-term experiences. Researchers have also critiqued the 'fast/slow' dichotomy that appears in the foundational slow technology article and challenged the dominant focus on treating 'slowness' as solely a matter of speed [126,179,181].

A primary goal of our article is to contribute to these emerging calls by extending a theory of slow technology for design through conceptual development by using an artifact analysis approach. The design-orientation of our work has made it possible to contribute a set of conceptual qualities that designers can work with. In this way, the primary goal of our work is to extend the design theory of the original slow technology vision. Along with numerous colleagues, over the past eight years we have adopted a reflexive designer-researcher approach in creating and studying slow technology design

artifacts. For our artifact analysis, we selected one artifact proposed in the original slow technology article –*Slow Doorbell* – and six slow technology design artifacts from our prior research – *Photobox*, *Olly*, *Slow Game*, *CrescendoMessage*, *Olo Radio*, and *Chronoscope*.

Adopting a designer-researcher position gives prominence to first-hand insights emerging through the creation of things that materially ground conceptual ideas through their existence. Designer-researchers often function as a small, often multi-disciplinary team that is critically focused on the experimental and novel outcomes of the design process that are arrived at through practice. Thus, this approach can contribute a first-hand and reflexive view of practices of making design artifacts in relation to higher-level theoretical concepts.

In what follows, we review works related to slow technology and temporality in HCI. We then detail our artifact analysis approach in relation to slow technology. For readability and to preface our artifact analysis, we briefly outline the conceptual terms that emerged through it. Then, we describe and analyse each design artifact in our collection. We conclude with a discussion that reflects on the extended concepts and terms that emerged through our artifact analysis and further detail how they might be mobilized in future research.

7.3. Related work

Temporality—the state of existing within time—shapes virtually all aspects of how we experience and construct the world around us. Time is fundamental to our existence. It is omnipresent. Thus, ‘time’ is a highly familiar phenomenon, yet challenging to pin down to a single definition. Scholarly inquiry into time itself comes with a complex dilemma: “time is both one of the broadest and richest topics, but also one of the most elusive” [133:6]. It is no surprise that there exists extensive literature exploring the concept of time from many perspectives across disciplines and fields including the humanities, social sciences, and physical sciences (c.f., [1,18,150,178,191,247]). In light of our specific focus on slow technology and design theory, an exhaustive review of differing theories of time is beyond the scope of inquiry for this article. It is nonetheless important to acknowledge a key sample of contemporary works that offer insights into some ways that time has been conceptualized and debated. In this, we touch on clock-

time and digital-time as two key conceptualizations of time (among many) to modestly situate our review of HCI and design research to broader ongoing discourse.

People's everyday lives are often surrounded and influenced by artifacts of clock-time – clocks, calendars, watches, and so on. These mundane temporal artifacts have long helped people to structure and coordinate their interactions and activities. However, scholars have argued that to 'know' the exact time, as measured and dictated by clock-time, is not inherently organic nor natural [117]. People's subjective felt experiences of time and the way in which they are objectified and segmented through clock-time, can differ substantially; and, this tension has received attention by researchers across numerous fields (c.f., [149,181,247]). Critiques of this tension have foregrounded the need to conceptualize time in more diverse ways outside of the 'hegemony of the clock.'[6] Through historical analysis, Glennie and Thrift [79] offer a salient critique of clock-time that situate it not as mechanistic and deterministic, but rather as a set of practices that evolve and change depending on the people, communities, and places within which it is situated. This shift toward viewing time as socially constructed and enacted is also explored through Birth's [18] connection of social practices with environmental and biological rhythms to account for the diverse nature of subjective lived experiences of time.

There also exist many works that have explored relations among digital media, technology and time. Douglas Rushkoff's [193] well known concept of "present shock" explores how the need for constant connectivity ushered in by digital technologies has amplified the reification of time by the clock and, in so doing, further diminished the availability of 'organic time.' This line of scholarly work is extended to further differentiate digital-time from clock-time through the always available and evolving information flow embodied in digital networked technology. People's exposure to rapidly expanding information that comes with digital connectivity can lead to lack of adherence to and abstraction from chronological clock-time. Through constant digital availability the present has 'caught up' with the future and this produces significant implications for how people perceive and identify time. Consequences from such digital availability can

[6] Deeper philosophical discussions on felt experiential or phenomenological time can be found in the works of Heidegger, Bergson, Husserl, and Ricoeur. See Martineau [134] for an in depth review of these philosophical lines of thought and their relation to earlier influential philosophical positions on time from Aristotle and Augustine.

generate an abstraction of digital information flows existing “outside of time, a sort of Dorian Grey existence, suspended in a continuous present” [88:2]. The consequences of digitally-mediated immediacy and availability, resulting temporal inequities, and their respective entanglements in the cultural politics of power relations continue to be major areas of scholarly inquiry and debate (c.f. [11,37,137,208,220,233,238]).

The development and formalization of theories of time is extensive; they go far back to beyond the time of Aristotle and contemporary theories are continuing to emerge in our lived present. From a high level, it is clear that time is situated, relational, and entangled; it cannot be treated reductively, and a diversity of perspectives are needed to conceptualize it. The connection among time and technology will continue to be the subject of ongoing discourse across many disciplines.

Naturally, time also touches on many core aspects of HCI research and practice. Interaction and graphical user interfaces are fundamentally temporal. Time is the medium through which an interactive dialogue between a human and computer begins, unfolds, and resolves. Early proposals such as Calm Technology [243] and the ambientROOM [106] ushered in interest in the HCI community around designing ambient displays—devices and applications that began to explore time in relation to peripheral information visualizations [132].

As focus in HCI expanded outside of the workplace, the need to more seriously consider the temporal dimensions of technologies in everyday life steadily emerged. This is summed up well by Mazé and Redström’s assertion that creating objects embedded with “computational material” requires designers 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*” [136:11]. This argument echoes Hallnäs and Redström’s (2001) earlier call for design initiatives to amplify and stretch *time presence* in everyday life, and reveal an expression of present time that is slower and, in this way, more subjective and socially situated. These issues remain important for the HCI community, and there has been a resurgence of interest in connections among slowness, time, and technology. A key strand of research has focused on how slowness can be an outcome resulting from technology use. Works in this area have focused on supporting experiences of mental rest [32,121,207], pause [237], and solitude [68].

Another area of work has investigated slowness as a frame for the design of interactive systems themselves. Drawing on Strauss & Fuad-Luke's principles of Slow Design [213], Grosse-Hering and colleagues [80] designed a series of juicers that aimed to support meaningful interactions by slowing down key parts of the juicing process. A study of the slow juicers found that participants preferred slow, mindful juicing activities *sometimes*—slow interaction was not perceived as appropriate during busy weekdays, but it was suitable on the weekend when causal time was more available. Slowness has been applied as a frame to explore strategies for extending object lifespans. For example, The Long Living Chair captures and displays the number of times people have sat in it over its lifetime. The Long Living Chair design raises questions around the role that a subtle yet explicit accumulation of one's history of use with a thing might invite care and maintenance over time [180].

Slowness has also been applied in a range of design efforts to support experiences of social connection over long time periods. For example, the Reflexive Printer [223] is a wooden thermal printer that randomly prints out black and white halftone pictures from the user's mobile photo album, and deletes the digital copy if the user does not scan the barcode of the picture. The researchers propose "perceived drawback" as a design quality to reframe technology-mediated reminiscence and build anticipation as an inter-subjective dialogue between people and technology develops over time. Slowness has also been adopted in the design of social messaging technologies to build anticipation in the communication experience. FutureMe [69] is an online messaging service that enables its users to send delayed messages by up to 60 years to their future selves or others via email. A study of FutureMe revealed that long-term time-delay between when a user wrote a message and when it was delivered prompted careful contemplation and intentionality in writing the message and led to range of emotional valencenes when messages were received—from the profound to the unsettling [154]. Similar to FutureMe, Postulator is a personal web-based application that sends photos or video clips to the users themselves or others via email after a time-delayed period [87]. Postulator explored how a slow, time-delayed pacing can stimulate reflective experiences such as the "perceived butterfly effect" where users intentionally tied together different periods from their past and contemplated how they might affect future social interactions with others. FamilyStories is a collection of tangible devices that explore how time-delayed asynchronous audio messages can support storytelling

among family members living in different time zones share [94]. A study of the FamilyStories system revealed that mapping time-delayed messages to different time zones that family members lived in often led to intimate and valuable interactions. Taken together, these works offer insights into potential benefits and challenges of the long-term use of a socially situated experiences of slowness and anticipation.

More broadly, HCI researchers have started to turn their attention to examining different perspectives of time. Lindley [126], Pschetz and Bastian [181], and Sengers [206] envision time as socially entangled and relational, highlighting the need for alternative expressions of temporality in design. Giaccardi [77] proposes *extended temporality* as combined cycles of pause and duration that, over time, lead to the accumulative development of shared social heritage. Taylor and colleagues [217] offer a rare account of a cross-cultural design project that emphasizes time from an Australian Aboriginal community's perspective. This work proposes an approach that moves away from treating time not as a discrete point on a digital clock or calendar, but rather as a socially shaped "set of converging circumstances that constitute 'the time' for happenings to take place" [217:6461]. Across several works, Friedman and colleagues sought to expand initiatives in HCI to consider multiple lifespans [63,64]. They highlight the need for new design methods to better engage with the challenge of designing in timeframes that may expand beyond the lifetime of the design team itself. In parallel, researchers have proposed different themes, such as biological time [116], narrative time [13], sequential time [130], time as social coordination [182] and ephemerality [47] as resources for design. While broad, these works collectively reveal a multiplicity of ways in which time can be viewed in relation to design that move beyond treating it as a matter of merely pace or direction.

The recent emergence of works in HCI related to temporality and slowness is valuable and encouraging. Yet, researchers and designers have also expressed struggles in creating technologies that sustain slower, longer-term experiences. Early works advocating for designing for slowness are somewhat abstract and there is a need to further address how to design for slowness on conceptual and practical levels [103,127,156,159]. The infrequent yet ongoing computational action of slow technologies can make it difficult to establish a sensibility for when the temporal pacing is 'right' [160]. Others have reported difficulties in aesthetically manifesting subtly changing computational actions in a resolved physical form [14,59] and in anticipating how

qualities of slow technologies might change over time in, and beyond, the design process [187]. These tensions highlight the complexity of designing technologies that deviate from enacting normative conceptions of time. This resonates with the work of Vallgårda and colleagues, who argue for designing the *temporal form* of computational objects, in addition to their physical form and interaction gestalt. They describe the need for design research to develop concrete examples of temporal form through "*comprehensive and intricate designs in which the material and physical forms expand beyond two-dimensional glass and plastic surfaces, and the interaction gestalt comprises more than look and point action*" [232:14].

Collectively, these circumscribed areas of work trace a trajectory of perspectives on time, temporality, and slowness in HCI and illustrate their continued evolution. They also highlight a relative shortage of research into slowness and temporality grounded in design practice. We see this issue as reflective of a growing concern in the HCI community on the lack of research that centres on the creation and analysis of design artifacts as a form of inquiry in and of itself. Our work aims to contribute to this area. We describe and reflect on theoretical insights that emerged through our artifact analysis of slow technology design artifacts. Next, we describe our artifact analysis approach.

7.4. The artifact analysis approach

Each of the design artifacts in our collection for analysis was designed with an aim to apply a framing of slowness as a critical lens to explore how longer-term relations could be better supported among humans and technologies. By primarily selecting artifacts from our prior research, we are able to report on first-hand insights in and across our collection. We situate the artifact analysis approach in the context of Research through Design (c.f., [72,248]) practice that contributes new knowledge in ways inherent to design methods, materials, tools, competencies that are essential in the making of design artifacts. This approach foregrounds the significance of the *reflexive practice of design* as being integral and essential to the potentiality of design to create research knowledge. This further extends a view of research from the perspective of design practice that provides the opportunity to describe and reflect on accounts of the messy interplay among theoretical ideas, design artifacts, and the first-person experiences of them. Thus, adopting an artifact analysis approach gives prominence to first-hand insights emerging through the creation of real things that materially ground

conceptual ideas through their actual existence—"*a process of moving from the particular, general and universal to the ultimate particular – the specific design*" [147:33].

In our case, this approach can contribute a reflexive view of design artifacts in relation to higher-level theoretical ideas that frame the creation of design propositions which, in turn, connect to specific, domain-level research questions. The goal of this process is ultimately to produce new concepts that can support new practices within an expanded design-oriented theoretical frame. We see this approach as being most closely aligned with HCI research that inquire into a type of design knowledge that lies between design theory and concrete design exemplars. Stolterman and Wiberg [212] see concept-driven interaction design research as research that addresses gaps in *design theory* between practical guidelines and established theories imported from other disciplines. Gaver and Bowers [19,71] and Löwgren [129] frame annotated portfolios as offering design knowledge that is situated within an intermediate-level knowledge in design research. We see our application of the artifact analysis approach to a case of slow technology as situated within intermediate-level knowledge [96]. We aim to extend a design theory of slow technology through an ongoing, piecemeal approach that leads to cumulative knowledge that, taken together, can further develop this program of design research [186].

We chose an artifact analysis approach as a way to establish a deeper understanding of slow technology and how it is represented in design artifacts and their intrinsic qualities.[7] Artifact analysis is an approach that supports a structured close examination of artifact examples to help facilitate conceptual development. It is a research tool that is primarily useful to develop, experiment with, and refine definitions of usable terms and concepts that can serve as a design-oriented theoretical foundation for determining and defining classes of artifacts and their intrinsic qualities.

The way we understand artifact analysis comes with some challenges. For instance, the notion of intrinsic qualities is problematic. Our way of dealing with this problem is to approach our analysis and the properties of the artifacts in the same way as a designer thinks about the artifact [see 108]. To a designer, the artifact is a thing that will be shaped and given certain properties and qualities. The properties and qualities

[7] Following Lewis [122], our use of the term "intrinsic" is in the philosophical sense – a quality that a thing has in-and-of-itself, independent of other things.

that the designer *can control* can be seen as *intrinsic* to the designed artifact. That is, when we analyze an artifact and its potential 'slowness' in relation to the theorization of slow technology, we only investigate qualities that can be shaped by the designer, and not qualities that are solely based on an end user's experience of or reaction to a design artifact.

Through its application, artifact analysis can iteratively lead to stable and well-formed definitions of artifact qualities that can inform the design of new artifacts. The outcome of an artifact analysis is critical and theoretical but it also has a practical purpose. It is *critical* in the sense that it intentionally challenges intuitive or everyday understandings of artifacts and their qualities, and makes it possible to ask new questions. It is *theoretical* in the sense that it leads to conceptual constructs that make it possible to more precisely define artifact qualities, their relationships and trade-offs. Our treatment of the term 'theory' is aligned with Gaver [72] and Redström's [186] related arguments that design theory should not be seen as conclusive and fixed, but rather as unfolding and transitional. We do not aim to create a comprehensive theory of design but rather view theory as "an annotation of realised design examples, and particularly portfolios of related pieces" [72:937]. By drawing on basic terms and definitions of slow technology as formulated in Hallnäs and Redström's [85] original visionary work, we aim to work toward more complex concepts through first-hand insights of design practice. Artifact analysis offers a structured approach to supporting this process. For the purpose of our research, our artifact analysis approach took the following form:

1. We started with a tentative definition of the notion 'slow technology' (primarily based on earlier research and literature, as presented in the 'existing definition' section detailed next)
2. We selected our set of artifacts to be part of the analysis (detailed in the following sections).
3. We carefully examined potentially 'slow' properties of each artifact in relation to the tentative definition.
4. We updated our definition based on the insights from each artifact analysis.
5. We repeated steps 3-4 until new insights from each analysis slowed down.
6. We critically revisited the initial theory (see revisiting the theory section) and extended it with our findings.

This approach occurred over the course of one year with the authors performing the analysis (as detailed in the steps above) and holding monthly meetings to discuss the relative stability and precision of the emergent conceptual terms. The approach looks simple and straightforward. However, it requires effort and a sincere ambition to be open-minded when it comes to recognizing and identifying new aspects of the theory that an artifact may bring. Careful investigation into the details of an artifact is necessary, and our process was shaped by iteratively oscillating back and forth between the conceptual and the actual, between definitions and manifestations. This required a detailed understanding of the theoretical concepts as well as of the material and functional aspects of the design artifacts in our collection. The artifacts each have a specificity to their performative and material arrangements and the qualities that are intrinsic to them. This is why we have primarily chosen artifacts that have been involved in our prior research. We already had an intimate and embodied situated knowledge about their designs and rationale. They are not the 'only' design artifacts that could be analysed and there are clear areas for future research to explore other design artifacts in relation to the design philosophy and theory of slow technology.

As a preface to what is to come, the design artifacts selected for our analysis are the following. *Slow Doorbell* is a doorbell that plays a short musical phrase of a much longer musical score each time it is pressed [85]. *Photobox* is a wooden chest that is connected to its owner's online Flickr photo collection that occasionally selects and prints a photo from the photo archive [160,164]. *CrescendoMessage* is a messaging application that lets the user send a photo to another person; however, the photo is initially visually obscured and, over time, it becomes clearer until it is fully revealed [29,222]. *Olly* is a music player that occasionally selects and offers the possibility to play a song that its owner had previously listened to at a specific point in time in the past [166,167]. *Slow Game* is a simple game embodied in the form of a small cube where the player can 'set' the next move but it will only be made every 18 hours [157,166]. *Olo Radio* is a music player that enables its owner to re-listen to music they have played previously through three different ways of temporally organizing the archive [158,169]. *Chronoscope* is a tangible, hand-held digital photo viewer synced with its owner's digital photo collection that allows them to explore and tune into possible known and unknown connections across their photos through different timeframe modes [31].

In our view, the artifact analysis approach was appropriate for our ambition to extend a theory of slow technology for design. Next, we offer a more detailed account of key propositions and qualities that formulate the initial vision of slow technology which is taken primarily from the foundational article where the theory was first presented. This is important because it primes the reader with the theoretical backdrop that is at the core of our analysis and which we aim to build on and extend through our work.

7.5. Slow technology: existing definition

In this section we distil how slow technology is understood and defined. We then return to this definition when revisiting how our proposed design qualities help to extend the original conceptual vision of slow technology as described below.

Core to Halläs and Redström's [85] argument is that, beyond designing 'calm' or ubiquitous technology that merely makes it easier to integrate technology into our everyday lives, design practice needs to change to actively promote moments of reflection and mental rest in the environments people inhabit. Slow technology aims to conceptualize technology in a way that invites people to critically consider and reflect on it in the context of their everyday lives. Against this backdrop, they raise the question: "*what are the characteristics of information and computing technology that initiate changes toward a more reflective environment?"* [85:202] and propose that the answer, in part, may involve adopting *slowness* as a core conceptual commitment in the design of technology. The conceptual idea of 'slowness' is situated in contrast to 'fast' technologies that are designed with efficiency and usability in mind. In Hallnäs & Redström's view, when people are able to complete tasks more quickly and efficiently, it takes time away "*both in terms of making the user more efficient when working (the task taking less time) and making the artefact as fast and easy to use as possible*" [85:203].

In contrast, slow technologies may *require time* to understand how they work and why they are designed in such a way. For example, consider the conceptual propositions outlined by Hallnäs & Redström: "*technology can be slow in various ways as it takes time to: i) learn how it works, ii) understand why it works the way it works, iii) apply it, iv) see what it is,* [and] *v) find out the consequences of using it*" [85:203]. Such *slow expressions* manifested by a slow technology may invite reflective experiences. When an invitation to directly experience or interact with a slow technology is accepted the

"time presence" of the artifact may become amplified as experiences of reflection unfold and one develops interpretations of the phenomena that they are encountering. In this way, slow technology has an accumulative quality – its character is not necessarily defined by a single interaction, but rather through the ongoing collation of experiences with it. Building on this foundation, Hallnäs and Redstöm [85] articulate three interrelated conceptual themes that support the *core vision of slow technology* and *what it aims to achieve*, which we summarize below.

Reflective Technology: designing technology that both invites reflection and, at the same time, is reflective in its expression. This means that a slow technology needs to support reflective and interpretive experiences while also asking questions about its existences as a technology. "*Here, the call for slow technology is to use slow design expression as an instrument to make room for and invite reflection; to use a slow presence of elementary technology as a tool for making reflection inherent in design expression*" [85:204]. The aim is to leverage the slow, evolving qualities of a technology as a strategy to open a space for reflection, both experientially and critically.

Time Technology: designing technology that "*amplifies the presence of time*" [85:204] and "*stretches time and slows things down*" [85:205]. This means creating technology that frees up time for particular kinds of things and experiences (e.g., reflecting on the past, critical interpretation, curiosity, prospective thought, and so on). Here, "*the call for slow technology is to design technology that in true use reveals a slow expression of present time*" [85:205]. The aim is to create technology that elongates time and, in doing so, makes space for pause and reflection as a key quality in design.

Amplified Environments: designing technology that amplifies the presence of things to make them into something more than merely a silent tool for fast access to something else. "*The call for slow technology is to use slow design expression to amplify given environments in time*" [85:205]. This speaks to the need to balance *presence* and *use* when crafting a design artifact and to carefully attend to the subtle integration of its expression within an everyday environment.

Hallnäs & Redström's original proposal of slow technology is a kind of "leitmotif" for interaction design. The three propositions above help conceptualize a vision of the design style, form, and expression of slow technologies. Slow technology offers an

important theoretical frame for questioning and expanding the role of technology in people's everyday lives. It offers a pathway toward transforming design practice beyond a sole focus on designing efficient, optimized, and easy-to-use tools toward creating technology that invites reflection as well as open-ended and ongoing engagements across long time periods. It critically positions people living with slow technology, and the technologies themselves, as co-shaping each other while more is learned and revealed through the accumulation of experiences over time.

While the initial vision of slow technology is inspirational and generative, it is worth revisiting and exploring how it might be extended with additional terms and definitions in light of more recent design artifacts that have been created since the original article. Challenges are also emerging among the design research community in creating slow technologies. Numerous international workshops have revealed that designers and researchers have struggled to put ideas of slowness into design practice [127,156]. Researchers have also critiqued the fast/slow dichotomy articulated in the original slow technology article, arguing it may be limiting and more diverse perspectives on temporality are needed (e.g., [159,181,182]).

Next, we briefly detail terms that help capture key qualities that emerged through our artifact analysis in order to prime the reader for the analysis that follows in the subsequent sections.

7.6. Key qualities emerging from our analysis

A set of key qualities of slow technology have emerged through our artifact analysis. Importantly, *these qualities did not surface a priori*. Before we move into our analysis, we want to briefly present these qualities since we believe that makes the reading of the analysis easier to follow. There are key connections and, in some cases, dependency across these qualities. They are not mutually exclusive, and it is not required that a design artifact exhibit all of them in order to be considered a slow technology. They are also not conclusive – more qualities may exist or emerge through the creation of new design artifacts. These qualities are closely aligned with Gaver's [72] articulation of Research through Design as a research activity that produces knowledge that is provisional, contingent, and aspirational. The qualities preserve and respect the ultimate particularity of each design artifact, while articulating theoretical concepts that

can connect and differentiate them. We believe they can help extend the existing understanding of slow technology because they offer terms that can further support the conceptualizing, designing and making of slow technologies. Before we move on we will define these key qualities. We are aware that these definitions may be difficult to comprehend without examples, but it is useful to have them presented before we move into our artifact analysis. The nine key qualities we have identified are listed in the following subsections.

7.6.1. Implicit Slowness

Implicit Slowness: a quality of a slow technology where end-user control has been intentionally designed into the artifact to enable direct modulation of its pace – one can 'speed it up' if so desired. Yet, by virtue of the design artifact's affordances, form and composition, it is unlikely this would happen and, thus, it retains a 'slow' character. In simple terms, this means the slow pacing of the design artifact is not enforced and can be freely controlled, but other qualities of the design artifact make speeding up the pacing less desirable, appealing, or intuitive.

7.6.2. Explicit Slowness

Explicit Slowness: a quality of slow technology where the designer has highly restricted end-user control over the design artifact. Its pacing and speed cannot be changed and, thus, the design artifact operates on its 'own time.' Explicit slowness manifests an unpredictable quality in the design artifact and can be used as a technique to design for cycles of anticipation and release.

7.6.3. Ongoingness

Ongoingness: the perpetual movement of time through an artifact that is subtle and gradual. The quality of ongoingness can have both explicit and implicit dimensions. Explicit ongoingness refers to the need for a period of time to pass for a design artifact to enact its computational behaviour in a cycle that is continuous and never ending. Explicit ongoingness is an important part of offering an invitation for engagement or interaction. There is less pressure or demand to accept the invitation because one can trust that eventually another invitation will emerge again in the future, although the specific point in

time that this will happen may be unpredictable and unknown. Implicit ongoingness captures the 'aging' and cumulative change of a design artifact over time. It refers to the ongoing, perpetual behaviour of an artifact that may not be immediately perceivable, but which plays an important role in shaping evolving relations to and perceptions of the artifact.

7.6.4. Temporal Drift

Temporal Drift: this quality refers to the temporal pacing of a design artifact's behaviour that makes it drift in and out of alignment with the cyclical rhythms and routines of a person's everyday life. Manifesting a temporal pacing that is different from an objectively recognizable form of time (e.g., the 24-hour cycle that makes up clock-time) creates an ongoing convergence and divergence of the actions of a slow technology and the actions of those that also inhabit the same shared environment. To achieve temporal drift, the artifact must have the *ongoingness* design quality. Temporal drift is also related to *explicit slowness* as a quality that can be used to design an artifact that intentionally manifests and operates on its 'own time.'

7.6.5. Pre-Interaction

Pre-interaction: a quality that explicitly emphasizes designing for the time and space prior to the moment that a design artifact is directly interacted with. This pre-interaction temporal space 'primes' the experience that one might have with the artifact, where the actual direct interaction may be quite minimal. Pre-interaction experiences can also be experienced entirely on their own and do not require direct interaction with the artifact for them to occur.

7.6.6. Temporal Modality

Temporal Modality: the application of different forms of time, linear and non-linear, as a central and defining quality of an artifact's interaction design.

7.6.7. Temporal Interconnectedness

Temporal Interconnectedness: the integration of two or more *temporal modalities* in a design artifact creates the possibility for temporal interconnectedness to emerge. This quality refers to the capacity to create a set of connections across different temporal dimensions simultaneously among different elements of digital media or data by virtue of the artifact's design.

7.6.8. Temporal Granularity

Temporal Granularity: a quality that enables the end user to 'tune' the amount of time that they move through when interacting with a slow technology that represents a digital media or data archive. Temporal granularity can be applied to address a friction (or frictions) that can emerge where temporal qualities of a design artifact create a dense time-related barrier that makes it difficult, if not impossible, to engage with a key aspect of the design itself over time. Tuning the temporal granularity of a slow technology opens up more freedom and flexibility for the user to move through large historical archives of digital content across time as slow or fast as desired and, in this way, opens up a different way that interaction pacing can be designed into slow technology.

7.6.9. Synchronicity – another key quality

An additional artifact analysis of PhotoClock supported me to observe an additional design quality named *synchronicity*, which expanded my understanding of how a slow technology could be designed. Here, I give a definition of it:

Synchronicity: a quality that highlights the concurrency of different perpetual movements of time by making the present flow of interaction synchronous with one or multiple designated periods in the past. Manifesting an interaction pacing that is similar to or the same as an existing temporal flow, such as clock time, creates a more dynamic sense of how temporality could be embodied, interconnected, interpreted, and reflected upon. To achieve synchronicity, the design artifact is required to have the qualities of ongoingness and temporal interconnectedness.

In our analysis below we will examine in more detail how these qualities can be understood. Some artifacts will relate to several qualities while others only to one or two.

These qualities are real, particular, and unfalsifiable; they aim to embrace design theory's provisional nature and diversity through grounding a specific set of design examples, while still remaining open for further theoretical ambitions to emerge from strings of design exemplars in the future (c.f., [72,186]). Thus, the qualities we detail are not the 'only' design qualities that can extend the original theoretical concept of slow technology. The purpose of our analysis is to extend the current understanding of slow technology, and how to surface and define a set of design qualities that can better support the creation of new slow technology design artifacts. Our aim is less to give complete and comprehensive descriptions of each artifact.

7.7. Artifact analysis

In what follows, we describe each design artifact in our collection and attend to key insights that surfaced through our artifact analysis. For each artifact, we offer an overview of what it does and a detailed analysis of how it negotiates and attends to slowness. Throughout this section, we make reference to the concepts described above and further unpack them by connecting these terms to the actual qualities of the design artifacts in our collection. Yet, before proceeding it is important to acknowledge the inclusion of the Slow Doorbell in our analysis which is a concept is taken from the original slow technology article. It was one of the first examples of slow technology and can be seen as the starting point for the theory of slow technology. This concept is highly inspirational and clear as a slow technology design exemplar, and, in our view it is worthy to be included.

The slow doorbell was never designed in practice in the sense that it was never made into a 'real' working prototype or product. Rather, it is a *design proposal* – something that does not yet materially exist and, in this case, was depicted through only verbal description. There is important value in design proposals precisely because they are somewhat open to interpretation and, as such, "allow for [their] consideration, discussion, and debate [where] the intended audience or users of design proposals are often [other] researchers and designers" [176:739]. We aim to consider and extend the Slow Doorbell design proposal within our analysis because its existence as a conceptual design proposal makes it more malleable to our own judgement and practice-based perspective on slow technology. The slow doorbell has also been highly influential in our design practice because, as we will unpack, it makes clear that slow technologies need

not solely ascribe to the fast/slow dichotomy, but rather can also be more openly manipulatable and continuous while still retaining the original visionary qualities of slow technology.

7.7.1. Slow Doorbell

In the original slow technology article, Hallnäs and Redström verbally present the "slow doorbell" as a conceptual design proposal [85:202]. When the doorbell is pressed, it plays part of the melody of a longer musical score for a short duration. Each time it is pressed, more of the musical score is revealed as it advances through the piece. Because it can be assumed the doorbell is pressed somewhat occasionally, then it would take time for a home dweller to understand the melody and the musical score as a whole through the gradual accumulation of experiences with it. As noted, the slow doorbell was never designed in a 'real' sense and exist as a design proposal; however, in our interpretation it offers a compelling early example of what the form, presence, and accumulative quality of a slow technology might be like. As an early example, slow doorbell illustrates how a slow technology can operate outside of the oppositional fast/slow juxtaposition and offer the home dweller direct control. That the slow doorbell exists as a conceptual design proposal has enabled us to think about it from our own interpretation and, in this way, flexibly extend it into our analysis. Thus, we decided to include it in our collection of design artifacts. It is an example of how slow technology was originally envisioned and, in this, offers the possibility to bridge our own work with an initial design exemplar that is open to interpretation and conceptual development.

The slow doorbell is 'slow' in the sense that it augments the somewhat infrequent activity of having one's doorbell pressed with a relatively brief snippet of a longer musical score. It *takes time to understand* what the musical score is. For example, we can imagine that if a five minute song played occasionally in 5 second increments when one's doorbell is pressed, then it would take a notable amount of time for the song to play in its entirety. It is also slow in the sense that it may take a substantial amount of time for a home dweller to understand or become familiar with the song. This could require a five minute song to be played through the doorbell in its entirety several times before a home dweller is able to recognize what the song is and where 'in time' the song is whenever the doorbell is pressed. Finally, the slow doorbell is emblematic of the original slow technology vision because it augments a common activity in a way that is

“time productive” -- it does not make the notification of a visitor to one’s home more efficient (or less efficient). Rather, slow doorbell augments this mundane activity to explore how it could be realized in a way that takes time, interpretation, and reflection to understand.

In our view, the Slow Doorbell can be seen as exemplifying the quality of *implicit slowness* because it is directly interactive yet assumed to be used only occasionally. This quality is in contrast to *explicit slowness* where technologies actively enforce a slow pacing and do not give the user control over changing it. One could imagine going to the doorbell and pressing it many times rapidly. As a result, in a relatively short time, one would know the song’s entire melody, thematic movements, and score. It is *implicitly slow* because its pacing could be easily modulated through user interaction and control. Initially, the musical score will be unfamiliar and unpredictable. The frequency of when musical fragments of the score will be played is also unpredictable as it relies on the recurrent, yet somewhat unpredictable return of visitors to one’s home. Thus, it changes over time as experiences with it accumulate and the musical score becomes more familiar to home dwellers (and perhaps to frequent visitors as well).

7.7.2. Photobox

Figure 31: The Photobox occasionally prints randomly selected photos from the user's Flickr collection. It can be opened to see whether or not a photo from the past is there.

Photobox is a networked device that is connected to its owner's online Flickr photo archive that is embodied in the form of an antique chest [160,164]. Each month it selects and prints 4 or 5 randomly selected photos from its owner's personal photo archive and prints each selected photo at a specific randomly selected time for that month. This process continues indefinitely. The user has no choice of what photos will be selected, when they will be printed, or how many will be printed each month (although it is always either 4 or 5 per month). The 'interaction' with the Photobox is simply to open it up and look inside to see whether or not a photo (or multiple photos) from your past are there waiting for you. In this way, Photobox does not demand nor require the user's attention in order to operate.

Photobox uses 'slowness' to engage with the abundance of digital photos that a person has accumulated and to make them scarce in printed form. It manifests an

explicit slowness because it has a pacing that cannot be modulated (i.e., it cannot be sped up or slowed down). Photobox combines a slow printing rate with multiple layers of randomness to make its behavior persistent, yet unpredictable. When these qualities are combined, they aim to manifest tension and trigger experiences of anticipation as the user will not know when a photo will print, where it will be from in their past, what will print next, and when it will come. Photobox continues its behavior indefinitely and, in this sense, manifests qualities of *ongoingness*. Photobox demonstrates *explicit ongoingness* in that the passage of time is required to trigger its behavior and, since it operates indefinitely (i.e., this monthly randomized cycle never ends), it manifests a form of subtle, yet perpetual change. Photobox offers an early example of *implicit ongoingness* because it is continually updated to reflect the most up-to-date index of the owner's Flickr archive; and, thus, each time it is encountered, it represents the slowly expanding totality of the user's digital photo archive. In other words, it captures the aging, cumulatively changing quality of one's digital photo collection each time one considers Photobox and decides to open it (whether one's photo collection is expanding or if it becomes diminished through personal deletion, data loss, or otherwise). On a technical level, it would be possible to open the Photobox and find a printed photo that the user had taken that same day or from many years ago. This quality of implicit ongoingness seen in Photobox helps capture how an artifact can manifest slow change over time that may not be immediately perceivable, while still viably evoking a feeling of continual evolution alongside the user through time.

Additionally, the extremely reduced 'interactivity' with Photobox (i.e., simply opening up the chest to look inside and see if a photo of one's past is waiting for you) was an initial attempt at creating a slow technology that foregrounds *pre-interaction* experiences. Pre-interaction is explored through intentionally requiring the user to open the chest and look inside while not providing any contextual clues as to whether a photo has been printed. In light of this design quality, prior to directly interacting with the Photobox, the user may anticipate or prospectively contemplate where in their life a photo might be coming from (if one has indeed been printed). This example helps start to show that the conceptual space *prior to interaction* with a slow technology can be a highly important area to attend to through design because it can open up rich possibilities to amplify time and prime critically reflective experiences with the artifact.

Pre-interaction is explored and conceptually developed further through other design artifacts that follow Photobox in our collection.

7.7.3. Olly

Figure 32: Olly is a music player that slowly surfaces songs that its user has listened to previously to be revisited and makes them available to be listened to again.

Olly is a networked music player that is connected to its owner's digital music listening history account data via the Last.FM service.[8] Similar to Photobox, Olly uses randomness as a design quality paired with a slow pacing to catalyze experiences of anticipation, interpretation, and reflection [166,167]. Each week, Olly randomly selects approximately 9 songs that were previously listened to by the user. The user does not have any control over what song from their past is selected or when. Importantly, when Olly selects a song, it does not immediately play it. Rather, it goes into a 'pending' state

[8] Olly (and also our Olo Radio design artifact) works by linking to a user's Last.FM account. Last.FM is a free web-based application that runs across a user's personal computer, smartphone, and peripherals to generate precise records of each song they have listened to in terms of the time, date, artist, song, and album (e.g., if listened through Spotify, iTunes, etc.). In existence since 2002, Last.FM offers unprecedented access to its users' listening histories. We also decided to use Last.FM data because it is a relatively open platform which makes it easier to work with listening history data (e.g., as opposed to Spotify or other listening services that do not allow end users to download or access their entire listening history data in a raw form).

where the internal disc of the device begins to rotate. The rate of rotational speed of the disc is based on how deep into the past that specific listening instance of the song was originally listened to. For example, if a listening instance was selected that is from deep in the user's past (e.g., many years ago), Olly will exhibit a slow rate of rotation compared to a listening instance that had been played much more recently. Supplying different voltage levels to the motor enabled us to change the speed of rotation. 4.4V is the lowest functional amount of voltage, which is used to represent the oldest instance in a user's database; it requires about ten minutes to complete 224 rotations. 12V is the highest (and represents the most recent instance of a song previously listened to); it takes about 4 minutes to complete the 224 rotations. Understanding the rotational speed relative to each specific music listening instance will likely require the user to take time to interpret and make sense of. Over time, these subtle differences may become more discernible and personally meaningful.

Olly also causes all instances in a user's database to slowly age over time because their 'age' is relative to today's current date. For example, Olly's absolute fastest rotation could only be triggered if it selected a song that the user had listened to in the past week. If new entries stopped appearing in a user's listening history archive, all of the songs in the Olly database would still continue to slowly grow older through the inevitable passage of time and irrespective of the actions of the user. Beyond the speed of rotation, no other information is offered about the specific listening instance when it is surfaced and made available to be played. This design decision was motivated by our desire to support a range of experiences with Olly that can evolve as one develops a sensibility for 'reading', interacting, and living with it over time. When a song is selected and if the user wants to play it, they then need to spin the disc and the song will begin playing momentarily. After the song finishes playing, the disc stops spinning and Olly shifts back into a static, passive state until another song is randomly selected. The process continues indefinitely.

Similar to Photobox, Olly uses 'slowness' to engage with the abundance of digital listening history data that a person has accumulated in their life by making situations in which they resurfaced and presented to be played through the artifact relatively scarce. Olly manifests an *explicit slowness* because it has a pacing that cannot be modulated. It also combines this slower rate of selecting songs with randomness to make its behavior persistent, yet unpredictable. When these qualities are combined, they aim to manifest

tension and trigger experiences of anticipation because the user will not know what song from their past will play if they trigger the rotating disc.

Figure 33: Left to Right. Olly can operate standing up (or lying flat); A pending song is played by gently spinning the rotating disc (pictured here when lying flat); Woodgrains move in and out of alignment as the disc rotates; Three Olly design artifacts.

However, different from Photobox, Olly aims to extend the *pre-interaction* experience by leveraging the actuated rotation of the internal disc to project a temporal expression associated with the specific listening instance that is being surfaced. This quality draws attention to how anticipation can be better primed and supported with a slow technology through *pre-interaction* (e.g., prior to when a song is played and one contemplates when in their life the song is coming from based on the subtle clue in the rotational speed). Photobox largely left it up to the user to wager a guess on if a printed photo from their past would be waiting for them by virtue of the enclosed, chest-like form. In contrast, Olly signals when a song from the user's past has been selected and subtly projects a temporal encoding through this signaling to open an invitation for the user to contemplate where in their past the rotational speed is associated with, prior to the song being actively listened to (should the user decide to accept the invitation in the first place). Olly demonstrates how *pre-interaction* can be a valuable quality for priming and supporting ongoing interactions with and experiences around slow technologies.

Olly also extended the temporal frame of interaction through expressing the relative 'age' of a listening instance through rotational movement that was continuous, interpretative and gradually shifting; and, which itself aged over time. The 'aging' of the listening history archive was expressed by the rotational speed for each unique instance becoming subtly slower as it grew older day by day.[9] As a material form, Olly was

[9] Although Olly randomly selects instances of songs listened to previously in its user's life and this data ages over time, the system structures the listening history archive chronologically. For example, when the user listens to music in their everyday life (outside of using Olly) and it is

designed and built robustly, not as a matter of permanence per se, but as a way to age and adapt to the passage of time; for example, the mahogany veneer gracefully ages and acquires a patina over time. These techniques of digital and material adaptation, combined with its unpredictable yet indefinite behavior, generate a sense of 'aliveness' in Olly whose combined physical materials and digital expression can slowly age alongside its user. Olly represented an up-to-date reflection of the totality of digital music listened to in its owner's life whenever it is encountered. Thus, the slow and gradual, yet consistent change through time amplified a sense of both *explicit* and *implicit ongoingness* as it continued to evolve.

Collectively, Olly represented a conceptual advance for slow technology that built on the Photobox in three key ways. First, it illustrated how a small degree of control could be extended to the user in a slow technology while still maintaining the quality of *explicit slowness* (i.e., the user could not change the pacing but could decide whether or not to play the song after it was selected and the rotation began). Second, it demonstrated how encoding the relative age of a listening instance, represented through its unique rotational speed, can be mobilized as a technique to support *pre-interaction* experiences that amplify Olly's time presence and can trigger reflective experiences. Third, it shows how integrating a slowly changing temporal expression, in this case an expression that is relative to today's date, can work as a resource to support the quality of ongoingness in slow technologies.

recorded in their listening history archive, these instances are simply the 'newest' ones introduced into the archive along a linear timeline. They do not form temporal connections to other songs in the archive except in relation to how old or recent they are to relation each other. The concept of *temporal interconnectedness* -- where digital media or data form connections across multiple dimensions chronological and non-chronological time simultaneously -- is motivated and exemplified later through the Olo Radio and Chronoscope projects.

7.7.4. Slow Game

Figure 34: Slow Game's gameplay unfolds slowly over time.

Slow Game's design inspired by and adapted from the Slow Games, an original art project by Ishac Bertran.[10] Bertran's project explored how a slow pacing could be applied to three different games: Pong, Tetris, and Snake. With this project, we initially aimed to produce a small batch of Slow Game research products to further inquire into slower-paced, yet ongoing temporal qualities and what might be revealed through applying them to a computational game that could operate over long periods of time. Out of the three initial games Bertran explored we decided Snake was the best fit for this project particularly because it does not require any additional interface controls or features (e.g., external knobs or buttons) which would enable us to craft an entirely uniform, embedded, and finished design artifact. The original snake game is a simple game in which a player maneuvers a fast-moving 'snake' (a thin line of pixels) that roams around on a 2D-plane with the goal of picking up 'food' (a single pixel). The user

[10] See Betran's website for in depth documentation and description of his original project that precedes the one noted here: http://www.ishback.com/slowgames/index.html

controls the direction the snake is heading. When the snake reaches a food pixel, its tail grows one pixel longer and another food pixel appears elsewhere. The player cannot stop the snake from moving while the game is in progress. The challenge is to make the snake avoid running into its own body or the perimeter of the 2D- plane; either case results in the game being over. Snake was popularized worldwide when it was included as a pre-loaded game on Nokia mobile phones in 1997.

The Slow Game research product is embodied in the form of a 5cm wooden cube [157,166]. It persistently displays the 'place' that the user is within a simple slowed down version of the snake game. The user navigates a 8x8 (64 pixel) matrix where the goal is for the Snake to reach 17 pixels long in order to win. The orientation of the slow game physical cube dictates where the next 'move' will go. However, the move is only made after an 18 hour period passes. Through iterative experiments, we lived with versions of Slow Game to explore different pacing cycles (e.g., 10, 14, 18, 28, 30, 50 hours, etc.). These experiences revealed that shorter phases (e.g., 10-14 hours) seemed to be too fast and multiple moves could easily occur before we noticed, while longer phases (28-50 hours) tended to feel 'too long' and, over time, caused the artifact to not be attended to for days, or to be largely forgotten. We found that an interval of one move per 18 hours created a dynamic, yet balanced quality of experience.

These experiences also revealed new tensions. We found that as Slow Game's snake grew longer and more visually complex, it became difficult to interpret which direction the next move would advance. It was clear some type of feedback had to be integrated to sustain intelligible, if not enjoyable, experiences with it. This prompted us to include a subtle feature in the design to clarify the cube's orientation: when it is rotated, the snake retraces itself pixel by pixel (one second per pixel), beginning at the tail and moving to the head. After reaching the head, it will blink three times in the pixel representing where the snake would move next. In this way, Slow Game communicates when it is tangibly manipulated to invite the user to check in on where the next move will go (i.e., effectively 'setting' the next move).

Yet, the user has no control over making the move actually happen. Slow Game becomes 'aware' at the precise moment when 18 hours have passed; it then senses its orientation, advances the next move, and becomes inactive for the remaining cycle. In some instances in the game, the 'best' or most optimal series of moves to win the game

in the most direct and shortest duration will require the user to simply leave the cube undisturbed for a series of days before another simple tangible manipulation of the cube is required. If the game does 'end' and the user loses, Slow Game goes into a 'mourning' state for 1 day (24 hours) and then the game restarts. If the user wins by making the Snake grow to 17 pixels long, then the game displays a visually pleasing, warm and slowly pulsing glow for 1 day and then the game restarts. In either case, this process continues indefinitely no matter whether or not there is any user interaction. In this way, Slow Game exhibits an explicit form of *ongoingness* because time is always perpetually moving through it.

Slow Game illustrates the quality of *explicit slowness* because it enforces a slow, although relatively predictable and visible pacing. The user cannot 'speed' the game up nor slow it down. It operates on 'its own time.' However, different from Photobox, it does offer some control in the design. The user may interact with Slow Game by tangibly manipulating it to explore different options for their next move as it re-traces its steps up to where the next move would land. However, the move will only be made after an extended duration of time has passed (i.e., 18 hours). This design decision builds in support for *pre-interaction* by enabling the user to explore and contemplate where they might 'set' their next move by manipulating the cube's orientation without knowing precisely when that move will be made.

Slow Game's pacing is intentionally designed to be offset from the 24-hour clock time. This design decision makes Slow Game *temporally drift in and out of alignment* with the user's everyday rhythms and routines. For example, the moment that Slow Game makes a move—and the clock starts counting down in the time window until the next move is made—might occur in the morning time when the user has recently awoken from a night's sleep. But as the days progress this moment will drift closer to the afternoon, then evening, then late at night, and so on. Thus, this quality creates a *temporal drift* that moves in and out of the 24-hour cycle of clock-time that people typically organize our lives around. This concept contrasts the *explicit slowness* of Photobox and Olly, both of which operate in an unpredictable way where their 'action' is only momentarily present in the printing of a photo or the rotation of the disc when a song is selected, and then they withdraw into a passive state in the background of daily life. Through its warm LED display diffused through maple veneer and the capacity for a user to manipulate it at any time to explore where their future move would land, Slow

Game persistently manifests a subtle presence. Because Slow Game operates on a different timescale outside of 24-hour clock time, the point at which the user would need to check to see if their move has been made is drifting in and out of the unique temporal rhythms of their everyday life.

In summary, Slow Game mobilizes qualities of *explicit slowness* and *ongoingness* in ways similar to Photobox and Olly. However, it differs by illustrating how *pre-interaction* can be a persistent, even interactive, quality through enabling the user to explore where their desired move may land as the snake retraces its path each time the cube is manipulated. The interaction makes clear to the user where the snake will make its next move, yet only through time and patience will the move be made, whether or not it is intentionally set by the user. Slow Game exemplifies the quality of *temporal drift* by manifesting its own time, in this case on an 18-hour scale, and perpetually moving in and out of alignment with 24-hour clock-time.

7.7.5. CrescendoMessage

CrescendoMessage is a digital messaging application that allows people to pick one photo and send it through one of its three obscuring lenses — *Gaussian Blurred*, *Crystallized*, or *Pixelate* — to another person [29,222]. In the original concept, the sender can select any temporal duration between one day to one year for the photo to slowly reveal its true unaltered form as it gradually becomes less obscured and more visible until it is fully revealed on the date and time selected by the sender. The user receiving the photo has no control over speeding up this process. The photo simply stays in their messaging application, visible at any time although its form may be obscured. Through time changing gradations slowly increase in fidelity, potentially prompting the user receiving the photo to prospectively reflect on what the photo content would be until the actual photo is eventually revealed.

Figure 35: Different types of obscuring lenses that can be applied to a photo via CrescendoMessage which will then slowly resolve to reveal the original image.

CrescendoMessage offers a constructive contrast to the Photobox, which uses time delay as the expression of *explicit slowness*. After the sender sets the time-delay period and selects the desired obscuring lens, only through an enforced amount of time will the photo be revealed. In this way, it demonstrates a 'crescendo' expression of *explicit slowness* that also supports *pre-interaction* through the receiving user not being able to control the photo but having the option to view the slowly changing gradational exposure of the photo as it becomes clearer over time. As an analogy to concepts for structuring time in music theory, Photobox's quality of *explicit slowness* can be seen as similar to *staccato* – indicating a sudden appearance in a short duration. In this view, Photobox occasionally prints a photo and then after an unknown, potentially significant amount of time delay occurs until the next one prints. Our messaging application gradually reveals a photo over time representing a *crescendo* form of explicit slowness that contrasts the examples of Photobox, Olly, and Slow Game.

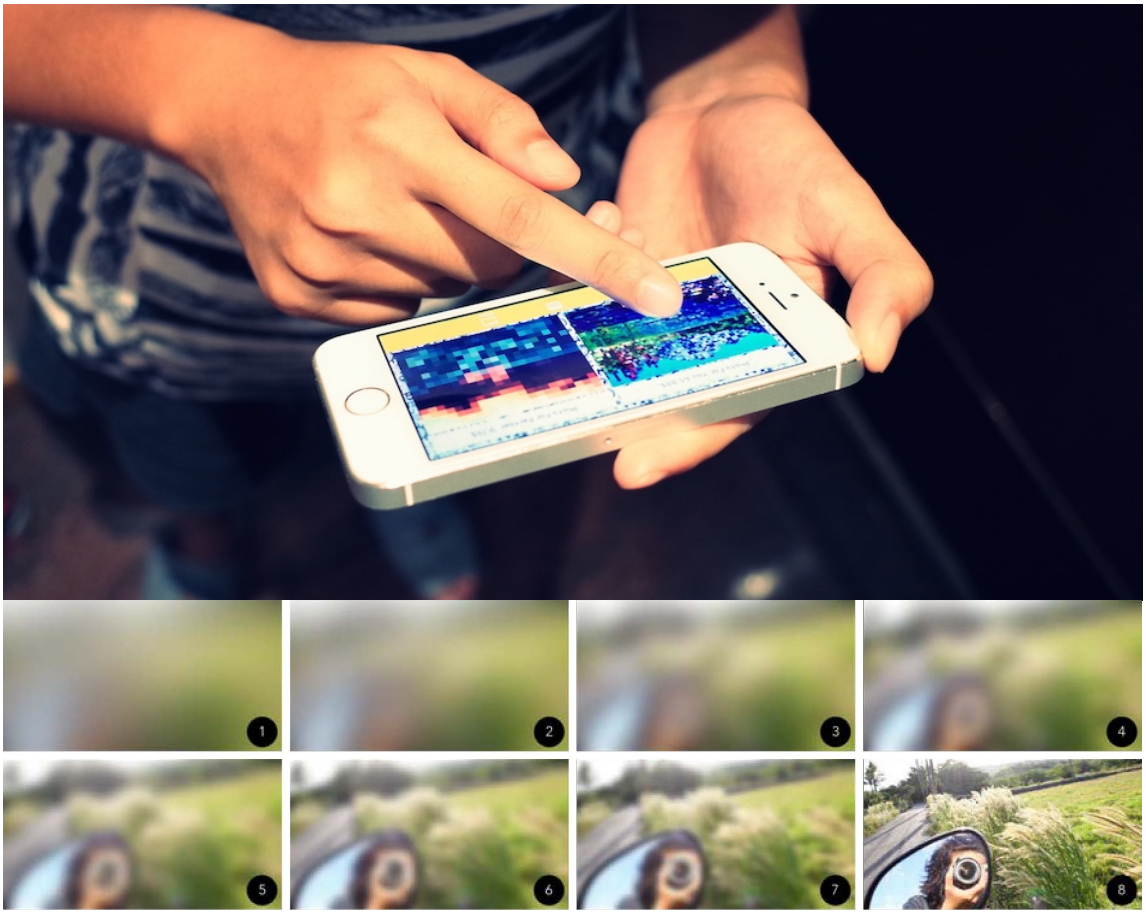


Figure 36: A scenario of the CrescendoMessage application in use and one example of gradual change over time when Gaussian Blur is applied to a photo.

In this way, CrescendoMessage highlights how gradational change can produce a gradual revealing temporal expression and alternative form of explicit slowness. CrescendoMessage also opens up new ways of approaching designing for *pre-interaction* and the role it can play in priming experiences with slow technologies, where direct interaction is a secondary concern. Photobox's capacity to support pre-interaction is highly restricted and solely relies on its form of a chest -- an enclosure that must be opened to see what is inside -- to potentially support pre-interaction. Olly supports pre-interaction explicitly but does so within a limited time window (4-10 mins). Slow Game also explores pre-interaction through direct interaction where the user can manipulate the cube to explore where the next move may go, but only through time (e.g., 18 hours) will the move actually be made. CrescendoMessage offers an example of how pre-interaction can be considered over much longer time periods (e.g., from one day to one year).

7.7.6. Olo Radio

Figure 37: Drawing on a user's archive of digital music listening history, Olo Radio embodies the lifetime of music a user has listened to.
The motorized linear slider and 3-switch knob exhibited on the left cabinet enable the user to explore, interact, and listen to music from their past across different timeframe modes; the rightmost knob controls on/off and volume.

Olo Radio is a music player that draws on a user's personal music listening history archive (via Last.FM) to embody the lifetime of digital music they have listened to [158]. Different from Olly, Olo Radio enables the user to have a high degree of control over the system. The two main points of interaction are the motorized linear slider and the timeframe knob (see the illustration in Figure 38). The timeframe knob offers the user three different *temporal modalities* that can be used to explore their listening history archive. The decision to make the timeframe knob a central feature in Olo Radio's interaction design enables the user to interact with music from their past through both chronological (Life) and non-chronological (Day, Year) *temporal modalities*. Different modes can be selected and toggled by the knob next to the motorized linear slider. The specific position of the slider is encoded to a specific 'point in time' in the user's past that is relative to the timeframe mode.

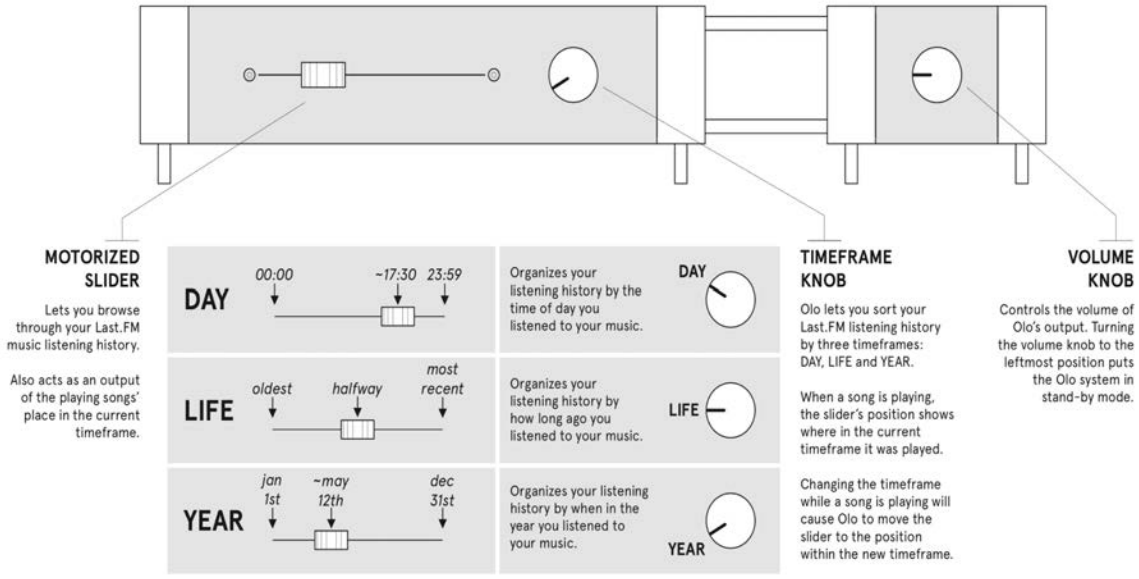


Figure 38: Explanation of the features, timeframe modes, and interaction design of Olo Radio.

When Olo Radio is turned on, it begins playing the song queried from the slider's current position. If left untouched Olo Radio will continuously play music, slowly moving forward in the timeframe mode. If the slider is moved, the current song will fade out and the song at the new location 'in time' it arrives at will fade in. If the timeframe mode is changed while a song is playing, it will continue to play as the actuated slider moves to the position in time where that instance is located in the new mode. In effect, the playing song remains unchanged, but the sequence of all listening instances surrounding it have been reorganized based on the newly selected mode. Olo Radio offers direct control to the user to change the timeframe modes and the position 'in time' that the slider represents whenever desired. This design decision creates an opportunity for the user to explore a range of possible connections across different songs listened to at different points in time in their past. Yet, Olo Radio's design is intentionally minimal. It takes time to understand, recognize, and interpret memories bound up in one's personal history.

In our original design we ensured that Olo Radio made daily updates to its database to capture new listening instances and then to evenly distribute all listening instances across 64 'containers' across the linear slider so that the same number of listening instances of songs were in each container. However, we found that even with a modestly sized listening history archive caused initial frictions in our design. For example, an archive of 50,000 unique listening history instances would take

approximately 45 hours of music continuously playing to make it through just one single container. While songs at the ‘front’ of each container might shift around to some degree when new data was added from the updated Last.FM archive, eventually a pattern in a specific ‘point in time’ that had been listened to several times previously would become quite recognizable. Practically, this meant that it was improbable that large amounts of music in the ‘middle’ and ‘end’ of the containers would ever be able to heard again. Conceptually, this meant that Olo Radio precise points in one’s past would only be available to be engaged with through a significant amount time and patience. We anticipated that Olo Radio would take time to understand, but we did not expect that frictions related to the temporal organization or each timeframe mode would be a point of friction.

These experiences prompted us to revisit Olo Radio’s design. We did not want to offer more end user control because we anticipated that this would detract too much from Olo Radio’s agency and, in this, comprise the qualities of unpredictability and change over time that are important for a slow technology. Yet, we needed to develop a technique to move through time in each container in a way that resurrected the many listening instances that were largely out of reach in the deeper temporal recesses of each container. We also needed to ensure that the unique sequential pattern was preserved from one song to the next. We eventually arrived an algorithm that applied a random selection to the where ‘in time’ music would begin playing from within a container. This only happened when the slider was tangibly manipulated by the user and moved to a new location Each time a new container is actively selected, Olo Radio will randomly determine where in time in the container it should begin playing from, effectively preserving the uniqueness of the temporal sequence, while avoiding being predictable.

As a design artifact, Olo Radio both builds on and departs from the design artifacts reviewed thus far in our collection. Photobox, Olly, Slow Game, and CrescendoMessage leverage *explicit slowness* to generate a pacing that is ongoing and offer differing degrees of restricted end-user control. In contrast, Olo Radio offers the user a high degree of direct control and also has no enforced pacing – the user is free to interact with it as much or as little as they desire. Yet, we carefully designed Olo Radio with conceptual propositions of the slow technology design philosophy in mind. It *embodies different forms of time* and makes them more present in everyday life through

the Life, Year, and Day temporal modalities. It also *requires time to understand* in important ways: 1) as the archive grows larger, the granularity across the slider timeline will slowly decrease and 2) the interface is highly minimal and offers no explicit information about the specific listening instance of a song that is being played. These design decisions aim to use minimal feedback to catalyze a range of experiences that can evolve as one develops a sensibility for 'reading' and exploring Olo radio over time.

Olo Radio's *temporal modalities* combined with its quality of *ongoingness* together open possibilities for one's relation to grow with it over time. It slowly evolves through updating daily to capture the historical traces of a user's music listening history. This means that Olo Radio always represents the totality of a user's listening history which effectively bridges it from the present moment when it is encountered to the past in an *ongoing* way. Olo Radio also subtly changes as the granularity of its slider gradually decreases as listening history data slowly stacks up across it. This, in turn, leads to a perpetual re-sorting of the sequential order of all listening instances which generates a quality of unpredictability that is uniquely tied to patterns produced from a user's own listening practices and accounts for the temporal density of the archive. The timeframe modes enable *temporal interconnections* to form and expand across all instances in a user's listening history simultaneously. For example, when a new listening instance is introduced into Olo Radio, it not only forms a relational connection to the other 'most recent' entries, but also to other music that was listened to previously at that specific time of the day as well as that time of the year. This quality of *temporal interconnectedness* may lead to relations forming among memories, experiences, and life stages that are bound up in the user's life history in chronological and non-chronological ways. This generates possibilities to explore alternative perspectives on one's personal history from various temporal vantage points and to manifest a cumulative sense of change across time.

Collectively, the design qualities of Olo Radio resonate with the original vision of slow technology, while offering new theoretical insights that can extend how we can approach it from a design perspective. Manifesting historical qualities of a personal archive through different temporal modalities can evoke a type of agency that is uniquely reflective of the user, that takes time to interpret, and that can scale and change over time. Due to digital music being an immaterial and temporal media, Olo Radio takes advantage of the time a user needs to 'spend' to listen, absorb, and interpret music

being played back from their past. The minimal interface design and actuated feedback can offer a quick ‘glance’ at where one might roughly be in time without demanding attention or the need for interaction. Next, we discuss Chronoscope which aims to adopt a similar approach used with Olo Radio and apply it to personal digital photo archives.

7.7.7. Chronoscope

Figure 39: Chronoscope is an interactive photo viewer that enables the user to re-visit and explore their digital photo archive through and across time.

Chronoscope is a tangible photo viewer that embodies the lifetime of digital photos a person has accumulated over their lifetime [31]. Chronoscope is synced with the user’s online photo storage archive (e.g., Google Photos, Dropbox) and enables the user to interact with their photo archive through three separate rotational controls: temporal viewing direction, timeframe modes, and viewing granularity. When peering into Chronoscope, a single photo tied to the specific time that it was taken, based on its timestamp metadata, is visible (see Figure 39). A rotating wheel, as the scope's main feature, controls two temporal viewing directions through a rotational movement (clockwise to move forward in time and counterclockwise to move backward). We selected physical rotation for this input as a subtle analogy to the circular shape of clocks and the temporal flow evoked by their movement. By rotating either direction, the user sees each photo in relation to a wide spectrum of other photos in the archive.

When the user stops the rotation, Chronoscope settles on the specific photo associated with where ‘in time’ the position is in relation to the selected timeframe mode. When switching the bigger knob on the side of the scope, users can seamlessly toggle

among different organizations of their archive through three *temporal modalities*: *linear*, *date*, and *time*. *Linear* organizes all photos in the archive in a linear timeline, from oldest to most recently taken. *Date* structures all photos in a temporal ordering based on the Month and Day they were taken irrespective of the year, potentially offering a more 'seasonal' way of exploring photos in one's archive. *Time* organizes all photos based on the specific time of the day they were taken irrespective of date or year, opening a space to explore the rhythms and qualities of past experiences captured in photos bound to parts of a user's 24-hour daily cycle.

A cornerstone decision in the design of Chronoscope consists of the following. When the user changes the *temporal modality*, the specific photo that is currently viewable does not change; rather, the organization of all of the photos around it changes in relation to its specific timestamp metadata. This enables the viewable image to act as an 'anchor point' through time and, in effect, empowers the user to explore a wide range of *temporal interconnections* between different photographs taken at different points in the user's past. We judged this to be an important and valuable design decision because it creates a space of possibilities for people to experience known or unknown connections among different photos and open possibilities to trigger experiences of interpretation, reflection, curiosity, or serendipity over time.

While the decisions described above reflect design qualities similar to Olo Radio, we encountered new tensions when grappling with the static and persistent qualities of digital photos displayed on a screen. For example, if a user has 20,000 photos and they aim to navigate to a specific time at the 'other end' of the photo collection, it would take approximately 2.77 hours to get there since each rotation moves through the photo archive by only one photo as a unit (and it takes about 0.5 second per rotation). With a larger archive, such as 200,000 photos the scenario is much worse (about 27.7 hours of continuous rotation).

This design issue revealed to us that we would need to build in a support for 'tuning' the number of photos that one moved through per each rotation. Different from how we grappled with the density of temporal metadata in the Olo Radio project, we could not rely on randomness or automatically 'shuffling' to a different point in time because it would be disorienting. Thus, we needed to enable people to move through their photo archives in very slow, precise, meticulous, and considered ways if, for

example, they encountered a set of photos that triggered deep reflection or required critical examination. Equally, we needed to provide quick movement across vast amounts of photos without an excessive amount of rotations, while retaining a subtle awareness of what had been passed over. In this way, Chronoscope demonstrates the quality of *temporal granularity*. With added control over the number of photos to be moved across in each degree of rotation, people would be able to 'tune' the pacing and speed through time that they move across their photo archive. The 'tuning' design element opens up more freedom and flexibility for the user to move through photos from minutes in a day to years of one's life, making it easy to slow down or speed up in real time. Ultimately, we found this design decision to be valuable in that it supports both movement across time (both the chronological and non-chronological modes) as well as movement through time in a combined and extended way.

Similar to Olo Radio, Chronoscope's design is highly resolved, while the user experience is largely undetermined and unstructured. It does not suggest where one ought to look in their past when deciding to engage with it. The design is relatively minimal and constrained, while it may give rise to various open-ended experiences—moments of curiosity, contemplation, and exploration. As a design artifact, Chronoscope makes use of *temporal modalities* to embody different forms of time and makes them more present in everyday life through the Linear, Date, and Time timeframes. It also leverages the combination of multiple *temporal modalities* with the quality of *ongoingness* to open up new possibilities for both chronological and non-chronological *temporal interconnections* to simultaneously emerge among digital photos in the archive through and across time. Chronoscope builds in support for tuning *temporal granularity* to open up added control and flexibility for the user to navigate possible *temporal interconnections* through and across time.

Chronoscope offers a complementary case to Olo Radio. Both design artifacts illustrate an extended way that slow technologies could be designed while also resonating with conceptual propositions core to the original slow technology design philosophy. They take time to understand, manifest change through time, and amplify time presence through their use, and reflection upon their place, in everyday life. They build on and help extend these propositions by manifesting different and multiple forms of time in ways that break down the dichotomy between slowness and fastness. In this way, they offer examples of how slow technology can be conceptualized beyond solely

matters of interaction speed, tempo, and pacing. Chronoscope and Olo Radio offer a high degree of control over the system paired with the capacity to develop cumulative change as temporal interconnections form across multiple dimensions of time, while still retaining the reflective, critical, and ongoing design qualities emblematic of slow technology's conceptual proposal and vision.

7.7.8. PhotoClock — another design artifact

PhotoClock is a mobile application that uses the current clock-time of the present moment to re-present people's photos taken around that same time of the day in the past. 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 *temporal modality* that expresses 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. *Hour* mode displays one photo per hour drawn randomly from the stack of photos taken at the current hour in the past. This photo will remain present until the current clock time turns to the next hour. 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. For example, 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. 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, and so on). It is possible that a photo will be displayed each second, continually moving forward in 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.

Figure 40: A Use Scenario of PhotoClock

While its interaction design is relatively minimal and subtle, PhotoClock takes time to understand and offers the potential to catalyze various open-ended experiences in relation to curiosity, contemplation, and reflection. Interestingly, PhotoClock represents a key difference compared to our research team's prior set of design artifacts in the journal article because it exemplifies a hybrid form of both explicit and implicit slowness. In the article, we clearly defined the qualities of implicit slowness and explicit slowness. While implicit slowness is a quality that lets the interaction pace of a slow technology to be freely controllable, explicit slowness enforces the interaction pace of a slow technology, making the technology operate on their 'own time' irrespective of user interaction. PhotoClock stands as a novel design case that reveals ways of integrating these two highly oppositional qualities. As time ticks away relentlessly, PhotoClock manifests *explicit slowness* by highlighting the ephemeral, indeterminate, and ongoing quality of time. It does not allow any user control over pausing, slowing down, or fast-forwarding the clock-time flow. PhotoClock operates indefinitely at the same speed as the present clock time flow, encouraging cycles of anticipation and release every 24

hours. In parallel, PhotoClock illustrates a quality of *implicit slowness* by providing three timeframe modes for its users to control the interaction pacing. This unique way of experiencing temporality is enabled by the fluid movement of time. For example, instead of interconnecting multiple dimensions of time through a selected digital instance based on its numeric numbers in relation to time (e.g., the date and time in the timestamps of a song or photo in the Olo Radio and Chronoscope), PhotoClock manifests three *temporal modalities* through a movement of time that continues endlessly but presents photo memories at different rates. Thus, this particular control of PhotoClock generates different expressions of slowness while enforcing the ongoing clock-time flow, making it a special design case that demonstrates how the two oppositional qualities can practically be leveraged together to create new interaction experiences.

PhotoClock's interaction design exhibits a quality of *explicit ongoingness* by not placing pressure on people to accept its invitation for reflection. That is, PhotoClock's recurrent cycle ensures that photos to have an equal opportunity to reappear around the same time of day, giving people the assurance that eventually, another invitation will emerge again. These constant opportunities and availability of revisiting photos over time bring the ongoing quality of time to the foreground. Meanwhile, PhotoClock is 'slow' in a sense that it promotes cumulative experiences of reflection through an unstoppable temporal flow, which leads to continuous revisitation of one's personal digital photo history that can slowly evolve every time people add a new photo to their archive. As a person accumulates more digital photos over time, PhotoClock updates its clock time-based library and shapes an evolving form of one's entire digital photo archive. This *implicit ongoingness* quality results in subtle changes in photo viewing experiences over time, which can be slowly perceived by people once new photos emerge and trigger different reflections on their own experiences. Together, the explicit and implicit ongoingness qualities in the PhotoClock design manifest the presence of time by fostering a sense of trust and anticipation for what might be unfold in future interaction.

PhotoClock primes people's *pre-interaction* experience through a combined use of staccato and crescendo forms, which we have mentioned before in the artifact analysis of CrescendoMessage [163:166]. When there is not a photo in the current clock time stack (i.e., a user is experiencing a 'temporal blank' of their photo history), PhotoClock gradually reveals the next upcoming photo. Similar to CrescendoMessage, PhotoClock applies blurriness to the selected photo as a subtle hint

to invite its user to slowly accumulate visual information of a memory. However, PhotoClock users can switch between ephemeral and lasting photo viewing experiences while experiencing a period of temporal blank through a change of mode. Ultimately, this particular crescendo form of interaction helps prime and support people's experiences of anticipation, curiosity, and reflection. But it was through the PhotoClock project that enabled us to consider how the quality of *pre-interaction* could be embodied more flexibly, dynamically, and interactively to create diverse paths for photo memories to be gradually revealed, anticipated, and reflected on.

Yet, unlike Photobox and Olly, which use randomness and a slow pacing to evoke anticipation and reflection, PhotoClock utilizes the clock time from the temporal metadata of one's photos to decide its timing of interaction. This approach of PhotoClock may enrich people's revisitation of digital photos and invites reflection on personal memories. This design decision leads to an expression of *temporal interconnectedness* that is manifested through a never-ending synchronization between the present moment and multiple past moments that were recorded around the same clock time. This synchronization empowers people to experience their photos alternatively through various temporal vantage points. Through a change of mode, PhotoClock not only switches the interaction pacing but selects a smaller or larger time stack to pick a photo from (i.e., the current hour, minute, or second stack). This dynamic way of interconnecting and resurfacing memories makes the timing of people's remembering process more traceable and ephemeral, inviting people to recollect their memories through the natural flow of time.

Similar to Chronoscope, PhotoClock manifests *temporal granularity* but through offering people a discrete and simple control of interaction pacing. PhotoClock's interaction pace is showing either one photo in every Hour, Minute, or Second (i.e., 1, 60, or 360) instead of allowing its user to see photos in a linear range of speed from 1 to 360. According to the findings of PhotoClock, when the granularities are not linear and are set by drastically different numbers, people could experience an intuition of desiring a more flexible 'refresh button' to look for other photo memories, but then a higher-level reflection of how the memories mean to them at the present moment would take place and engage them to think about the forever ongoingness of life. Although the granularities of time in the Minute or Second mode are not easily perceived and recognized by people, it is through this kind of tensions that prompted people to think

about how they remember things and how temporality could come into play when it comes to personal reflection on life history.

In summary, PhotoClock not only mobilizes qualities of pre-interaction, temporal interconnectedness, and temporal granularity but also stands as an interesting example of manifesting both the qualities of explicit and implicit slowness, as well as the explicit and implicit ongoingness. The design case of PhotoClock helps reveal that these seemingly oppositional qualities, if treated carefully, could be preserved in a single design artifact in valuable ways. Therefore, PhotoClock further advances our understanding of the slow technology theory by showing that there can be less rigidity and opposition in manifesting these higher-level design qualities and creating opportunities for exploring how to combine them in future research work. Also, PhotoClock provides minimal controls that allow people to focus on the memories themselves, which exemplify how the ongoing movement of time could be used to design a temporal modality that leads to more dynamic memory-oriented interaction compared to the ones manifested in our other previous slow technology design artifacts.

7.8. Revisiting the theory

The contributions of this research offer an extension of the existing theory of slow technology as well as a number of design artifacts that each represent some key dimensions of the theory. These contributions are closely related and interdependent. Artifact analysis requires a detailed understanding of theoretical concepts as well as the design artifacts themselves. The selection of artifacts is crucial and this is why we primarily selected design artifacts that we had first-hand knowledge about. If other artifacts were selected, other design qualities may emerged and this suggests clear opportunities for future research. We do not see this as problematic since our aim is not to present our extension of the theory as conclusive or finalized. Our goal is to derive theoretical insights that can support, extend, and further diversify the conceptualization and design of slow technology. We see our work as an invitation to others to conduct similar research that explores the value of the theoretical concepts and to potentially develop other forms of extensions.

Based on previous work in the field, we summarized the theory of slow technology as consisting of three interrelated conceptual themes that together support a core vision. This vision defines slow technology as:

Reflective Technology: designing technology that both invites reflection and is equally critically reflective on technology through its expression.

Time Technology: designing technology that makes space for reflection through embracing different forms of temporality as a key quality in design.

Amplified Environments: designing technology that amplifies the presence of things to make them into something more than merely a silent tool for fast access to something else.

Based on our research, we still find the core vision of slow technology as relevant, generative, and theoretically stable. From a high-level, the new qualities inspire a different way of viewing design and influencing a designer's attitude. Through our research we have extracted nine artifact qualities that can contribute to and extend this core vision. These qualities are different from the visionary themes; they are *design qualities* since they can be controlled by a designer to be more or less present and explicit in an artifact. The nine qualities are: *implicit slowness*, *explicit slowness*, *ongoingness*, *temporal drift*, *pre-interaction*, *temporal modality*, *temporal interconnectedness*, *temporal granularity,* and *synchronicity*.

We believe that extending the initial theory, which is quite abstract and mostly on the level of intention and ambition, with our more concrete, design-oriented qualities makes the overall design theory of slow technology more robust and useful. The theory becomes more robust through connecting an abstract vision with concrete examples and by exposing the theory to a number of artifacts. Through this process, we get a clearer sense of what are key core aspects of the theory and also what might constitute weaker aspects of it. The extension also makes the theory more useful simply because it relates abstract concepts and ideas to qualities that can be controlled and worked with by designers. Next, we revisit and reflect on proposed qualities in light of our artifact analysis and the core vision of slow technology.

Implicit slowness shows that, on a general level, slow technologies can be freely controllable and that slow interaction is not merely a matter of speed. It foregrounds the need for designers to consider how a design artifact's affordances, form, composition, and presence holistically come together to support an accumulation of interactions that gradually reveal its character over time. Implicit slowness opens a space for designers to explore how artifacts can be designed that may not be interacted with every day, week, month, or even year, but which are open to direct interaction at any time and which are continually returned to over time through sustained and recurrent experiences.

Explicit slowness offers a contrasting quality where slow technologies are designed to intentionally restrict end-user control as they operate on their 'own time' irrespective of user interaction (or even the presence of others). It offers a framing that designers can scaffold to expand beyond designing for immediate response time and to explore crafting a temporal pacing that is distinct and indeterminate. Explicit slowness emphasizes the co-habitational aspect of slow technology where an artifact oscillates in and out of perceptual view in everyday life through moments of action and sustained periods of inaction. As this process unfolds, relations to and perceptions of the slow technology may change and grow richer as experiences accumulate around it. Explicit slowness also prompts designers to closely attend to how they surface and balance unpredictability in the artifact as it signals and enacts its slowly paced behavior.

Ongoingness brings attention to the movement of time through an artifact and how this, in turn, shapes the artifact's design and evolving expression. Ongoingness is closely linked with artifacts that exhibit *explicit slowness* because it speaks to the subtle, yet perpetual and never-ending nature of their behavior. This quality is important for creating slow technology because it can evoke a recognition by the user that the artifact is continually changing alongside them, albeit at its own pace. While greatly restricted user control is often exhibited in artifacts that are explicitly slow, over time the quality of ongoingness may help generate a deeper understanding of an artifact and alleviate tensions that may initially emerge from a lack of end-user control. Ongoingness also extends to artifacts that are not explicitly slow by prompting designers to develop techniques to project the co-evolving, aging quality of an artifact through time even if this subtle cumulative change is not always immediately perceivable.

Temporal drift leverages qualities of *ongoingness* and *explicit slowness* to explore the relationality among cyclical forms of time that operate on different tempos (e.g., the 24-hour clock-time that many people organize their everyday lives around contrasted with a different yet stable tempo). Such juxtapositions can productively generate a sense of ongoing change in a design artifact as it drifts in and out of alignment with periods of times when the user is in its proximity. Designing a different, yet stable temporal pacing in relation to clock-time into an artifact offers an alternative approach to supporting an ongoing cycle of anticipation compared to using randomness to generate unpredictability in a slow technology.

Pre-interaction refocuses attention to the expanded set of experiences that could be considered and designed for prior to interaction with the artifact itself. For example, anticipation is often characterized as two temporal phases: the first, before an experience happens as tension builds, and the second during the experience as one reflects on what has been revealed through interaction. However, the first temporal phase of anticipation has often been overlooked in HCI and design, and remains underexplored. The extended temporal frame offered by pre-interaction points to how design artifacts, through different temporal expressions, can catalyze a rich range of experiences prior to interaction and that lie outside of direct interaction.

Temporal modality foregrounds the integration of one or multiple different forms of time as the cornerstone of an artifact's interaction design. For example, temporal modalities can be applied to organize digital media or data in ways that are not random but may still be unpredictable and apt to catalyze anticipatory, reflective, and interpretive experiences. Integrating temporal modalities as a defining quality of interaction opens up another alternative way for designers to conceptualize slow technologies that moves away from treating slowness as simply a matter of speed in opposition to fastness. Chronological timescales such as time of day, month, or year and other non-linear forms of time, such as lunar, biological, geological or deep time can be explored as generative resources for crafting and applying diverse kinds of temporal modalities in designing slow technologies.

Temporal interconnectedness arises as a quality that can be explored and manipulated when two or more temporal modalities are integrated into a design artifact. This situation opens the possibility for interconnections to form and expand across all

instances of digital media or data embodied by a design artifact across multiple dimensions of time. The simultaneous and ongoing formation of interconnections across time can project a co-evolving quality that is unique and distinct to the user, that takes time to interpret, and that can scale to evoke cumulative change over time.

Temporal granularity extends control to the user to 'tune' the relative amount of time that they move through when performing an interaction with a slow technology. Particularly in the case of design artifacts that embody large, dense archives of digital media or data, this quality enables users to tune down the granularity of the interaction to slowly explore and attend to very specific time periods represented in the archive. Equally, it enables the user to tune up the granularity to fluidly navigate across vast time periods. As experiences accumulate with tuning temporal granularity and a user becomes more familiar with this quality, they may develop a sensibility for their own desired interaction pacing when moving through time periods and across interconnections stitched together through multiple temporal modalities.

Synchronicity inherits the quality of ongoingness and temporal interconnectedness by manifesting an endless movement of time that presents digital media or data in one's archive through a sequence of temporal anchors (e.g., photos taken in an order based on their timestamps). Importantly, this quality allows people to move through data fluidly in a constant speed and highlights simultaneous presentation of data and time. This constant co-presentation of data and temporality invite users to create associations and comparisons between the present moment and past life events. Through synchronous movements of time, people are enabled to experience a recurrence of memories themselves and a potential refreshment of memories that renews what had been remembered and felt in the past. Although a simple control of regulating the interaction speed could be enabled as an add-on to allow more flexible and curious exploration (e.g., the Hour, Minute and Second mode in PhotoClock), synchronicity is a quality that aims to minimize control, putting users in a constructively 'accepting' or 'passive' mindset, where they were able to let go of control, receive a trigger from their past, and reconstruct their memories in a self-determined and ongoing way.

In summary, the theoretical contribution that we offer directly builds on the three original visionary themes of slow technology and extends this foundation through nine

design qualities. Each of the nine qualities relate to one or more of the visionary themes. Additionally, each of the design qualities relate to each other in complex ways. As an initial step, the goal of this article is to describe and unpack each of the nine qualities in relation to a key set of design artifacts. Future research can further investigate what the interdependencies and relations may look like among the qualities, but we anticipate that there are many combinations and that there are potentially serious trade-offs involved. For instance, combining and exemplifying all qualities in a single design artifact likely is not possible; certain combinations or strengths of qualities might even be counterproductive or cancel each other out. Additionally, we have not yet examined what might not be covered with these nine qualities. There is an opportunity to investigate this question through selecting a new set of artifacts for analysis and to explore comparative conceptual connections and differences. One approach could involve selecting a collection of different slow technology design artifacts. Another approach could consist of selecting a set of artifacts that do not exhibit any signs of slow technology, or that might be contrary to slow technology. Such artifact analyses could challenge and explore the stability and extensibility of the nine design qualities, and may lead to further insights about them as well as new theoretical concepts that our analysis may not have captured. There are clear opportunities for future research to both build on and challenge our findings.

7.9. Conclusion and future work

We have offered an extension to the design theory of slow technology. Our aim was to build on the original theory of slow technology and the core vision that its visionary conceptual themes mobilize. A key goal of our research is to articulate new qualities that help extend this vision and enable the theory to be more robust and useful by making it more practically accessible to designers and design researchers. To achieve this goal, we have developed and refined nine design qualities through a careful artifact analysis approach and presented a detailed analysis of eight artifacts that exemplify key aspects of the extended theory.

So, what does an extended and more detailed design theory of slow technology mean to the field?

First, it helps further open up and develop the slow technology design space. The foundational themes of Reflective Technology, Time Technology, and Amplified Environments are highly generative, and they are also highly abstract. Design researchers and practitioners have encountered difficulties in translating these themes into the particularities of design practice in the crafting of new design artifacts. The nine qualities developed and articulated through our research aimed to be a more design-oriented extension of the slow technology vision. Importantly, it is not required for all qualities or a finite number of qualities to be represented in a design artifact for it to be considered "slow technology." Rather, designers and design teams can use this extended theory to raise certain questions about whether a particular quality exists in an artifact that they are designing and the extent to which it should or should not be emphasized. This will help support various stages of the design process by assisting design decision making earlier in the design process when assessing possible design alternatives and variations in the divergence phase. This extended theory will also help later in the convergence phase when assessing specific design qualities as slow technology artifacts move toward finished form.

Second, we believe that our work will better support academic researchers and creative practitioners to analyze design artifacts based on the expanded theory. It provides a foundation for considering what a theory of slow technology might be, might be missing, or how it can be further developed. We have worked under the assumption that when a theory is extended – made more precise and concrete – it also opens it up for critique. We believe clear concepts and definitions are easier to analyze and critique than broad abstract intentions. We see our work as a piecemeal advance in a longer-term process towards conceptual clarity and invite others to engage with it. We hope that the original design theory with its extension will be seen as a contribution to the field that needs further examinations and analysis.

We also believe that engaging with the artifact analysis method was the appropriate methodological fit for this kind of research. We selected this method because we needed an approach to develop conceptual insights from a range of artifacts with the purpose to develop a theoretical understanding across these artifacts. The artifact analysis method enabled us to re-examine designs that we already knew intimately and to inspect the artifacts through a theoretical lens that led to further refinement of the design theory and the emergence of new concepts. In a field like HCI,

where research deals primarily with designed artifacts, there is a need for an approach that can support theoretical and conceptual development through an investigation of a category of designs by careful examination of individual artifacts. Outside of slow technology, we believe HCI research has a number of ‘theoretical’ candidates that would be suitable to approach using an artifact analysis method. We hope the artifact analysis approach can be appreciated as an effort to better support reflective forms of knowledge production in the HCI community.

In conclusion, our proposal for an extended theory of slow technology is an invitation to others to further build on, extend or challenge the theory. HCI research is a field that is about the new, the next, the future, and has arguably engaged less in cumulative knowledge building. Our research is an attempt to build theoretically on what has already been done in the field to extend previous work. We hope that our work will entice others to do the same.

Chapter 8.

Conclusion

To conclude this dissertation, I summarize its contributions by revisiting each research question. Then, I summarize the limitations of this work and describe my critical reflection on the challenges and opportunities that emerged. This serves as a way to propose potential directions and starting points for researchers who are interested in exploring new digital photo viewing experiences through the expression of time.

8.1. Contributions — revisiting the research questions

At the time I began my doctoral research, the field of HCI had already given considerable attention to digital photos for purposes such as self-identification [40,41,89,236] and collective remembering [5,21,45,46,145,235]. Researchers had taken approaches such as investigating digital photos as memory cues [100,112,196,244] and enabling new tangible and embodied interaction design [162,174,222,228,246]. Yet, these investigations had largely focused on creating and evaluating new experiences of revisiting a single or a small set of photos. Few works had explored alternative ways to support people to make sense of their exponentially growing digital photos over time. This prompted me to critically consider the overarching research question of this dissertation:

How can memory-oriented experiences with personal digital photos be supported and sustained as digital photo archives grow, expand, and age over time?

To answer this question, my dissertation makes three contributions by providing:

1. *research products* that offer concrete examples and practice-based insights for future researchers to take consideration when designing technologies for reflection,

2. *empirical data* from field studies that provides better understandings of people's lived experience with the proposed research products, and

3. *design qualities* for extending the design theory of slow technology through a variety of temporal frames.

In sum, two research products named Chronoscope and PhotoClock were created and deployed in our research participants' houses to collect empirical data. Together with other cases in our design research lab, Chronoscope and PhotoClock supported us to conduct an artifact analysis and distill a series of design qualities that pushed the development of the slow technology design theory. Throughout my research path, my overarching research question gradually evolved into 5 distinct subquestions, each of which was addressed and answered in Chapter 3 to 7. Next, I outline each contribution made in the process of answering these 5 questions.

RQ1: What opportunities exist to leverage 'temporal metadata' as a design resource that supports memory-oriented ways of experiencing the trajectory of digital photos one has accumulated in their life?

As Chapter 3 shows, this research question came into place after I studied numerous works in HCI and the social sciences in relation to digital photo viewing experiences and personal data. At that time, the research communities had an emerging interest in using data as a design material. Yet, there were very few design cases to engage deeper discussion about how this approach could support the design of technologies for people to make sense of their vast and still growing digital possessions.

Therefore, I formed a design research team and created Chronoscope, a tangible photo viewer that allows people to re-experience their accumulating digital photos in a more diversified way. From paper sketching, digital prototyping, software programming to digital fabrication and production, we batch produced a number of Chronoscope research products and reflected on our own relationship with digital photos through the process of making and experiencing them over time. Through the Chronoscope design process, this work produced two contributions:

- Providing a design case that enables people's interaction with massive digital photos through and across time, and
- Investigating temporal metadata as a design resource and suggesting temporal granularity as a way to resolve the 'stuck in time' and 'lost in time' tensions.

Findings shows that temporal metadata offers a range of possibilities for us to explore memories, either known or forgotten, and to make connections across non-linear temporal trajectories of one's personal photo archive. Compared to the use of

randomness as a well-accepted way to invite surprise and reflection in interaction design [119,120,124,188], the use of temporal metadata was a rather new approach that echoed with and suggested by prior works [82,158,170]. This approach allowed users to perceive and build more precise relations between individual digital photos through and across time. Importantly, we observed and reflected on the tensions related to the scale and temporal dimensions of digital photo archives, namely the 'stuck in time' and 'lost in time' experiences. Through overcoming these tensions in practice, our work suggested that tuning temporal granularity could be a viable option for future HCI researchers and practitioners to grapple with similar interaction issues.

RQ2: What are viable conceptual frameworks for conducting practice-based design research that utilize notions of time to invite one's reflection on their vast and still growing digital photos?

After the Chronoscope design study was completed, my second research question emerged through me and my supervisor reflecting on our particular designer-researcher approach to producing a series of time-related interaction design artifacts [155]. As noted in Chapter 4, with an aim to contribute to methodological development and introducing our approach to broader design communities, we collaborated on a book chapter on practice-based research that made the following contributions:

- Introducing the generative role of a designer-researcher approach, and
- Unpacking four conceptual frameworks we resonated with and applied in our approach behind the scenes of our Chronoscope design process.

We introduced our designer-researcher approach by providing four related concepts that inspire and situate our position: *research through design*, *autobiographical design*, *reflective conversation with materials*, and *research product*. By giving a concise review of prior works and using Chronoscope as a design case, we explained how these four points could came together to support a first-person practice-based design research inquiry in relation to temporality. Through unpacking the details from a methodological perspective, I started to see a bigger picture of potential opportunities for bringing philosophers, social scientists, and design practitioners to collectively develop new ways of grounding theoretical concepts related to time through creative practice.

RQ3: What memory-oriented photo viewing experiences could be supported and sustained through a tangible photo viewer that allows people to explore their digital photos chronologically and non-chronologically?

To address this third research question and expand our understanding of how the Chronoscope interaction design could support people to explore their digital photo archives, I deployed four Chronoscopes in four different households in Metro Vancouver area for three months. We recruited participants who had constantly used Google or Dropbox to back up their digital photos for years and had thousands of photos in their cloud service. Semi-structured interviews were selected as the data collection method for this study to provide in-depth knowledge of the topic. This empirical study created three contributions:

- Using temporal metadata as a memory cue to create and trigger journey-based exploration in one's life history,
- Providing ways to support people's exploration of potentially forgotten or unknown life patterns over time, and
- Extending the conceptual lens of slow technology through developing more diversified strategies to design with temporality.

The result of this field deployment study in Chapter 5 shows that Chronoscope catalyzed a range of reflective experiences on their respective life histories and life stories. It opened up alternative ways of considering the potential longevity of personal photo archives. In particular, participants experienced a journey-based interaction with their entire personal digital photo archives, in which they used both chronological and non-chronological timeframe modes to navigate unique pathways through multiple memories and life stages. Using temporal metadata as a memory cue to trigger this type of experience, Chronoscope exemplified a way of designing malleable forms of time to bring more curiosity, anticipation, and reflection into people's interaction with their massive digital photos.

RQ4: What opportunities exist to leverage 'current clock time' as a design resource that supports new ways of experiencing the trajectory of digital photos one has accumulated in their life?

The findings and limitations of Chronoscope primed my research inquiry to the fourth research question, which investigated how the perpetual movement of time can be

leveraged as a unique resource to continually connect the present moment to people's photos taken around that same time of the day in the past. As noted in Chapter 6, to address this objective, I created another research product named PhotoClock, a mobile application that leverages temporal metadata to connect the present moment to one's past memories. I deployed this app to 12 participants who are iPhone users located in North America and have at least one thousand photos on their devices. Semi-structed interviews were conducted online after 8 weeks of usage in field. The main contributions of this work are:

- 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, and
- Extending the conceptual lens of slow technology through developing diverse strategies to design with temporality.

In addition to temporal metadata, the use of the present clock time as a design resource allows the PhotoClock design to enable a strong and ongoing connection between the present moment and one's life history bound to their large and still growing digital photo archives. The minimal controls provided by PhotoClock also encouraged participants to engage in the process of perceiving and reflecting on their photo memories. This finding extends Axtell et al.'s work [5] that argued the combined lack of *user control*, *visual context*, and *manual curation* were what made photo viewing applications often not effective for remembering the past or for spontaneous reminiscence. On the other hand, participants reported that witnessing the '*temporal blanks*' in periods when they did not take any photos in their life created room for them to make rich interpretation and inference. Thus, using the empty spaces of one's digital photo archives to design novel photo viewing experience could be a promising way to develop more diverse strategies to design with temporality for personal reflection.

RQ5: What opportunities exist to extend a theory of slow technology for interaction design through more diverse and expressive design qualities in relation to time?

After going through a research trajectory built upon the original slow technology concept published in 2001, our research team conducted an artifact analysis on 7 design

artifacts and proposed 8 design qualities to extend the theory of slow technology in 2022. In addition to the 8 qualities, I proposed a quality of synchronicity derived from the PhotoClock project (2023) in this thesis. The main contribution of answering this question is to offer an extension to the design theory of slow technology with the set of qualities listed below:

- *Implicit slowness*: a quality that lets the interaction pace of a slow technology to be freely controllable.
- *Explicit slowness*: a quality that enforces the interaction pace of a slow technology, making the technology operate on their 'own time' irrespective of user interaction.
- *Ongoingness*: a quality that brings attention to the movement of time through the subtle, yet perpetual and never-ending nature of a slow technology. It exhibits explicit slowness and makes a technology continually changing alongside people.
- *Temporal drift*: a quality that leverages ongoingness and explicit slowness to explore the relationality among cyclical forms of time that operate on different tempos.
- *Pre-interaction*: a quality that refocuses attention to the expanded set of experiences that could be considered and designed for prior to interaction with the artifact itself.
- *Temporal modality*: foregrounds the integration of one or multiple different forms of time as the cornerstone of an artifact's interaction design.
- *Temporal interconnectedness*: a quality that arises as a quality that can be explored and manipulated when two or more temporal modalities are integrated into a design artifact. This situation opens the possibility for interconnections to form and expand across all instances of digital media or data embodied by a design artifact across multiple dimensions of time.
- *Temporal granularity*: a quality that extends control to the user to 'tune' the relative amount of time that they move through when performing an interaction with a slow technology.
- *Synchronicity*: a quality that highlights the concurrency of different perpetual movements of time by making the present flow of interaction synchronous with one or multiple designated periods in the past.

8.2. What's next? — limitations and future work

To create new experiences of digital photo wayfaring, my doctoral research brings together and extends a range of previous studies of slow technology and temporal interaction design. Here in this section, I critically reflect on my entire research trajectory and discuss the limitations as well as the opportunities for future HCI and design research.

In my dissertation, there are a number of research limitations that need to be addressed. First, there is a main limitation inherited from the RtD methodology, which is its lack of extensibility [72]. While embracing the benefit of exploring a 'wicked problem' through the creation of design artifacts, the artifacts' uniqueness made the extensibility of knowledge less possible. Second, RtD studies that involve producing the research products and deploying them to people's houses in field usually require much longer time and higher cost. Third, the small sample number and unique profiles of participants in the field deployment research approach had led to results that are not generalizable to a broader population [23]. Fourth, I mainly focused on participants who have skills and access to technology and have accumulated a certain amount of digital archives in North America. Hence, insights derived from my dissertation may not be applied to people from different regions or cultures.

Next, I discuss what future directions could be considered to continue the investigation of exploring temporality for digital photo wayfaring.

8.2.1. Exploring alternative sources and creative integration of temporal metadata to design for human-photo interaction

Among the works completed in my PhD research, I have observed several challenges and opportunities in relation to temporal metadata. In particular, I learned that designing different forms for temporal metadata could bring people valuable digital photo viewing experiences. While Chronoscope had enabled a journey-based viewing approach for one to revisit their lives in unique pathways, PhotoClock had created flow-based experiences that invited one's deeper reflection on how memories come and go dynamically as the perpetual movement of time continues. These two design cases exhibit how the concept of data wayfaring could support and engage people's interaction

with their vast and still growing digital photos. According to the concept of *data wayfaring*, instead of following a set path to an imagined future, people navigate (in their digital data archives) using a variety of information, cues and intuition as best as they can for the purposes of knowing themselves — a life being lived. [189]. Despite taking different approaches, Chronoscope and PhotoClock both enabled people to creatively explore and reflect on their life histories bound up in their digital photo archives in a sequence that interconnected or flowed photos through the presence of time. Importantly, addressing the ongoing quality of change in one's digital photo archives generated possibilities for renewed curiosity over time. Thus, leveraging temporal metadata to design human-photo interaction does create new ways for people to understand themselves and reflect on their life stories shaped by the entirety of digital photo archives.

Yet, memorable moments in relation to digital photos are not restricted to the time a photo was taken. There are design opportunities for other temporal metadata than the 'creation date' of a digital photo. Prior works suggested that people's engagement with digital photos involve activities performed after the moment of capture [115]. These activities include searching, selecting, organizing, editing, and sharing [22], during which the digital photo file can generate temporal metadata such as 'modification date', and 'last opened date'. These temporal metadata are traces of people's intimate interaction with their digital photos. Similar to how the Olly and Olo Radio projects manifested one's music listening histories for personal reminiscence, metadata like these can be valuable for designing innovative memory-oriented photo wayfaring experiences. A potential direction to investigate in the future is to allow revisitation of one's photo sharing history, in which they could experience collective remembering with their loved ones through and across time.

Throughout my PhD research, I also learned that the existing timestamp formats are quite finite and relatively inflexible, which could lead to potential issues in relation to integrating photos captured in diverse time zones and calendar systems. For example, participants did desire ways to explore memories experienced in the Iranian calendar or the lunar calendar. This shows design opportunities to explore more diverse approaches to integrate and manifest temporal metadata as memory cues in the design of digital photo technologies.

8.2.2. Extending the design theory of slow technology through more design cases that apply diversified and malleable forms of time

In conclusion, over the years I have studied various design perspectives [50,125,212] that triggered me to rethink not only the theoretical development through an alternative lens [96,239] but also what real-world technology design could supports people's understanding, exploration, and speculation on the potential meaning behind data. Although the creation period of research products can be long and at times difficult, it is ultimately a rewarding process. These research products have created new human-computer interaction experiences and supported my understanding of how temporality could come into play to support longer-term human-technology relations. The findings and design qualities derived from my research projects were completed with a hope of making contributions to the HCI design and research communities in a way that offers an alternative lens of designing technologies for digital photo wayfaring.

Collectively, my accumulated works published throughout my PhD study have indicated the value and need to extend the design theory of slow technology. To advance this development further, the HCI and design communities would need more design examples that showcase how more diverse and malleable forms of temporality in the design of technologies could create meaning to people and their important others [30,181,185]. While personal data and digital possessions are growing inevitably to support our utilitarian needs, we are gradually learning to co-exist and evolve alongside these overwhelming resources, seeking better ways to navigate them over time. Data wayfaring provides a way to look at our histories bound to these digital archives, both at a macro and micro level, and create journeys that human brain alone can struggle to process without the support and power of computing technologies. But still, questions continue to emerge:

How much wayfaring control should be provided in the interaction design of a slow technology to engage people's exploration of their digital possessions? How to mobilize and extend diverse temporalities across different forms of personal data?

While the HCI and design communities may already have some insights, these ideas will continue to evolve as time progresses, very much like memories, which cannot be recorded in any digital form, but are reconstructed every time they are recalled.

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