Chronoscope: Designing Temporally Diverse Interactions with Personal Digital Photo Collections

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ABSTRACT
With the massive proliferation of digital photos, new approaches are needed to enable people to engage with their vast photo archives over time. We describe the Research through Design process of 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. We unpack and reflect on design choices that made use of digital photo metadata to support new ways of interacting with personal photo archives *through* and *across* time. We conclude with opportunities for future HCI research and practice.

Author Keywords
Digital Photos; Metadata; Temporality; Interaction Design.

CSS Concepts
• Human-centered computing~Interaction design process and methods

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 [7]. 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 [49].

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., [70]). 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., [12, 44, 60, 61, 66, 67]). 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).

Figure 1: 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.

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 [15, 45]. 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*" [39, p.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?

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Figure 2: 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 turquiose eye piece thorugh a magnication lens, the user views photos from his past. **Right:** The user manipulates a black metal knob that 'tunes' the grainularity of photos that moved through in each rotation; the untouched knob toggles between timeframe modes.

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 1).

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 3). 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 2). 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 2).

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.

Figure 3: The Chronoscope UI visualizes the central photo's location in time and provides corresponding data around it.

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 [1, 8, 26], supporting self-growth [9, 38] and shaping people's transitions and development of a cohesive life story [28, 29, 52, 53].

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 [4, 5, 41]. Building on earlier research on *PhotoWork* [34], the recent work of Broekhuijsen et al. [5] 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 [2, 22, 44, 60, 61]. 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., [2, 44, 71]). 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 [27]. 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 [32, 67], provoke social conversations [25, 30], and support collective experiences of reminiscence and reflection [25, 32, 44, 48, 60, 61, 65, 66, 71].

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 [13, 23, 45]. Through the Curatorial Agents project, Gulotta et al. [23] 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. [45], 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 [43]. 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*" [24]. 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., [6, 25, 46, 60, 61]). 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 [68]. In parallel, Pschetz [51] 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 [62]. Albeit from a different perspective, this argument resonates with Huang and Stolterman's work [31]. 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 [16] 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. [19], Sengers et al. [57], Zimmerman et al. [72], Bardzell et al. [3], and Stolterman and Wiberg [59] 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 [17, 18, 33, 50]. 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.

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*" [42, p.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* [63, 64] 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 [20, 21], reflective design [57], and slow technology [24]. 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., [3, 10, 16, 59, 72]). 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 [54], 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.

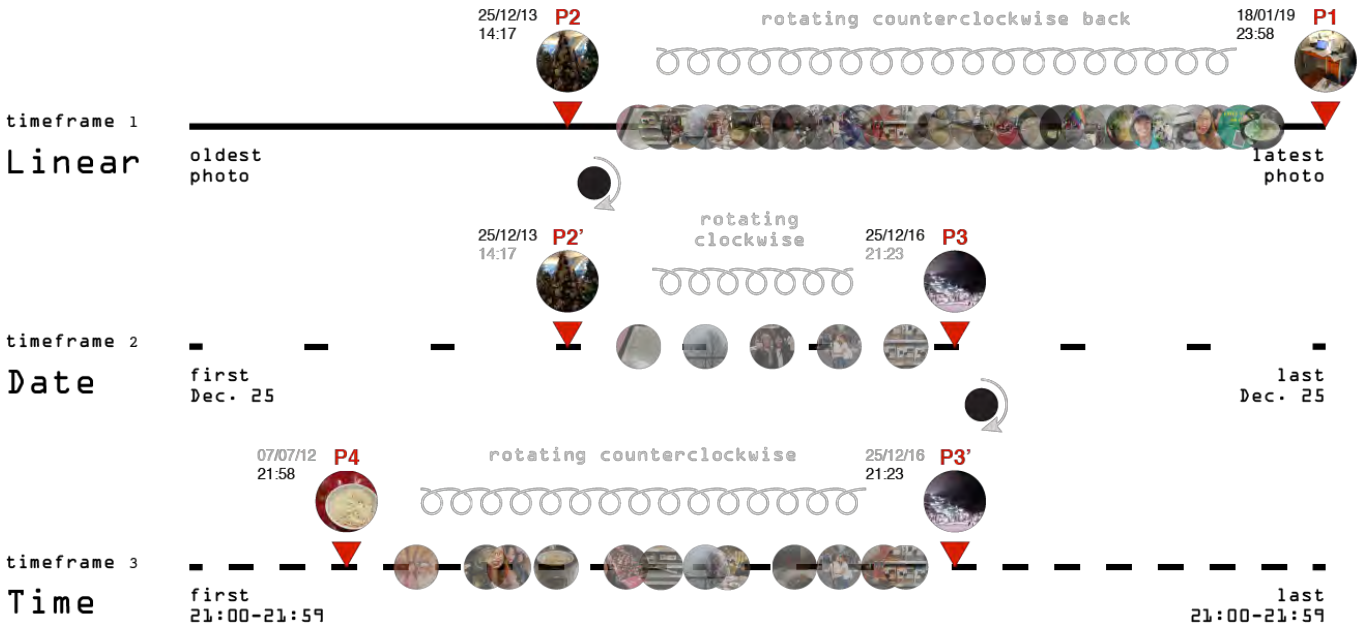

Figure 4: Scenario of moving across the three timeframe modes. Imagine a user turns on Chronoscope and begins at P1 (on the top right) in the *Linear* timeframe. She rotates counterclockwise back in time to P2, and shifts to *Date* mode, where she can see the surrounding photos are replaced with other 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.

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

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		

Table 1: Partial EXIF data that could be used as design materials (* prone to support people's contextualization of memories)

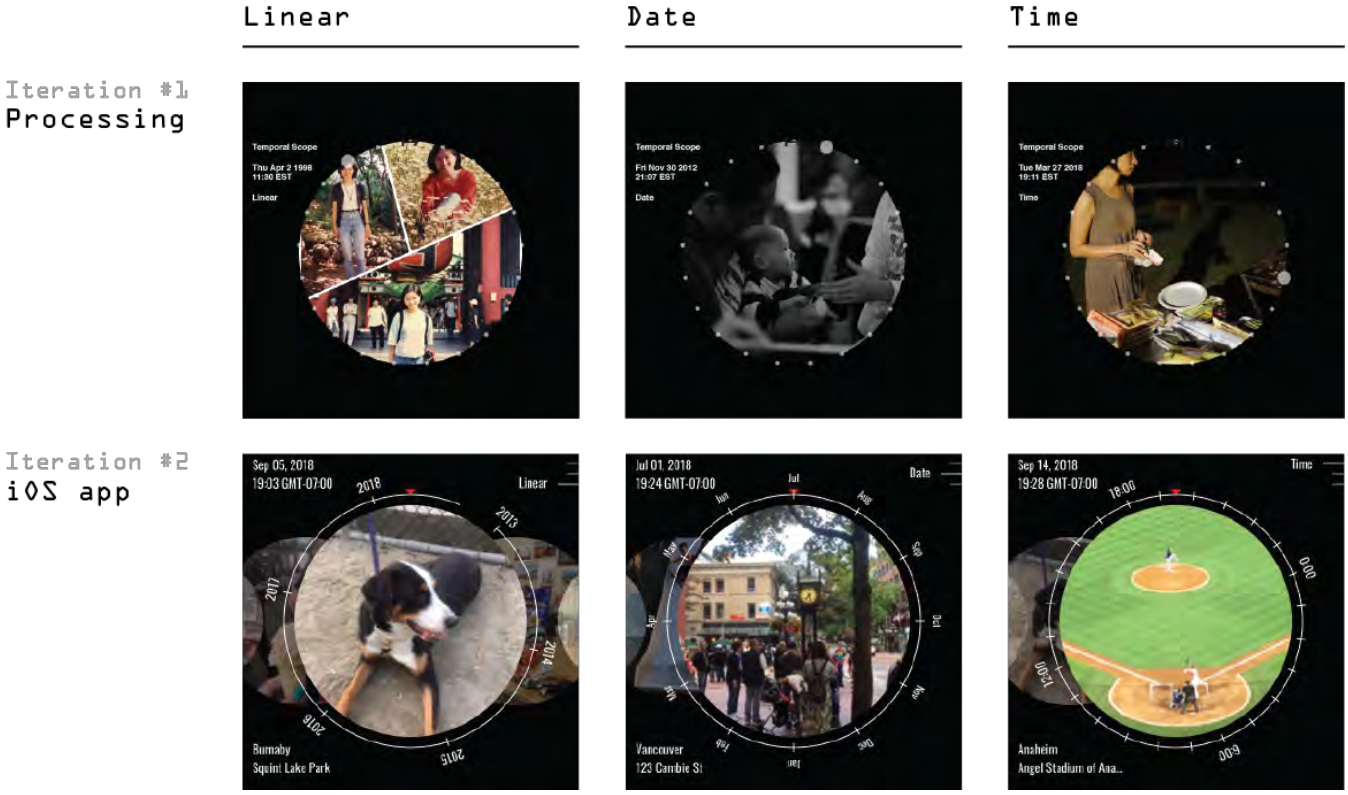

Figure 5: The evolution of the Chronoscope user interface. During the first iteration with the Processing app, we listed the metadata text of *time of day* and *date* into two different rows (see upper left) that incidentally revealed intriguing ways to apply and structure metadata in our second iteration (bottom left). The final design shown in Figure 3 is modelled after iteration 2.

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).

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 5). 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.

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 4.

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 5) 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 5 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 5 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.

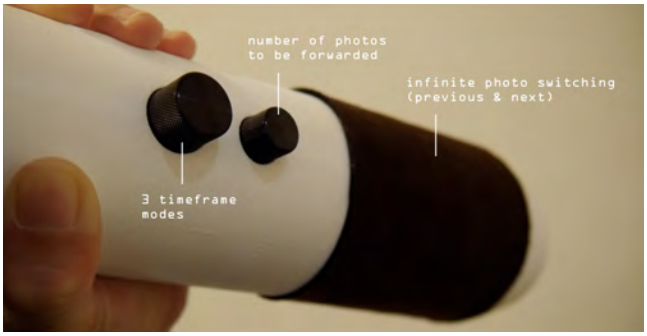

Figure 6. Three physical controls used to select viewable photo, timeframe mode, and to *tune* the temporal granularity.

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* [20, 21]. 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 7). Throughout the ideation process, we looked toward the aesthetics, functions and the human-object relationship of various types of scopes for inspiration.

(a) Rotation (b) Kaleidoscope [58] (c) Telescope [33]

Figure 7. Form and Interaction Design 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 2-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 6).

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.

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.

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 [46, 61] and more generally digital media [35, 36]. 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.).

Investigating metadata as a design resource

Building on prior work [43], 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* [23, 43, 45], 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 [14, 15]. 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 [11, 47, 55] that could be leveraged in support of future research in this direction, as could research on developing tools for designers [40, 58].

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 [15, 44, 56] and b) expressing more diverse perspectives on temporality through design [37, 51, 69]. 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.

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REFERENCES

[1] Amber L. Cushing 2014. A Balance of Primary and Secondary Values: Exploring a Digital Legacy. *International Journal of Knowledge Content Development and Technology*. 3, 2 (2014), 67–94. DOI:https://doi.org/10.5865/IJKCT.2013.3.2.067.

[2] Banks, R. and Sellen, A. 2009. Shoebox: Mixing Storage and Display of Digital Images in the Home. *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction* (New York, NY, USA, 2009), 35–40.

[3] Bardzell, J., Bardzell, S. and Koefoed Hansen, L. 2015. Immodest Proposals: Research Through Design and Knowledge. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (New York, NY, USA, 2015), 2093–2102.

[4] Broekhuijsen, M., van den Hoven, E. and Markopoulos, P. 2017. Design Directions for Media-Supported Collocated Remembering Practices. *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, 2017), 21–30.

[5] Broekhuijsen, M., Hoven, E. van den and Markopoulos, P. 2017. From PhotoWork to PhotoUse: exploring personal digital photo activities. *Behaviour & Information Technology*. 36, 7 (Jul. 2017), 754–767. DOI:https://doi.org/10.1080/0144929X.2017.1288266.

[6] Cheng, J., Bapat, A., Thomas, G., Tse, K., Nawathe, N., Crockett, J. and Leshed, G. 2011. GoSlow: Designing for Slowness, Reflection and Solitude. *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (New York, NY, USA, 2011), 429–438.

[7] Csikszentmihalyi, M. and Halton, E. 1981. *The Meaning of Things: Domestic Symbols and the Self*. Cambridge University Press.

[8] Cushing, A.L. 2013. "It's stuff that speaks to me": Exploring the characteristics of digital possessions. *Journal of the American Society for Information Science and Technology*. 64, 8 (2013), 1723–1734. DOI:https://doi.org/10.1002/asi.22864.

[9] Cushing, A.L. 2011. Self extension and the desire to preserve digital possessions. *Proceedings of the American Society for Information Science and Technology*. 48, 1 (2011), 1–3. DOI:https://doi.org/10.1002/meet.2011.14504801304.

[10] Dalsgaard, P. 2016. Experimental Systems in Research Through Design. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2016), 4991–4996.

[11] Dove, G., Halskov, K., Forlizzi, J. and Zimmerman, J. 2017. UX Design Innovation: Challenges for Working with Machine Learning As a Design Material. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), 278–288.

[12] Durrant, A., Frohlich, D., Sellen, A. and Lyons, E. 2009. Home curation versus teenage photography: Photo displays in the family home. *International Journal of Human-Computer Studies*. 67, 12 (2009), 1005–1023.

[13] Elsden, C., Kirk, D., Selby, M. and Speed, C. 2015. Beyond Personal Informatics: Designing for Experiences with Data. *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems* (New York, NY, USA, 2015), 2341–2344.

[14] Elsden, C., Kirk, D.S., Durrant, A.C. and Chatting, D. 2017. Designing Documentary Informatics. *the 2017 Conference* (New York, New York, USA, 2017), 649–661.

[15] Elsden, C., Selby, M., Durrant, A. and Kirk, D. 2016. Fitter, Happier, More Productive: What to Ask of a Data-driven Life. *interactions*. 23, 5 (Aug. 2016), 45–45. DOI:https://doi.org/10.1145/2975388.

[16] Fallman, D. 2003. Design-oriented Human-computer Interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2003), 225–232.

[17] Faste, H. 2017. Intuition in Design: Reflections on the Iterative Aesthetics of Form. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), 3403–3413.

[18] Friedman, B. and Yoo, D. 2017. Pause: A Multi-lifespan Design Mechanism. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2017), 460–464.

[19] Gaver, W. 2012. What Should We Expect from Research Through Design? *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2012), 937–946.

[20] Gaver, W., Boucher, A., Bowers, J., Blythe, M., Jarvis, N., Cameron, D., Kerridge, T., Wilkie, A., Phillips, R. and Wright, P. 2011. The Photostroller: Supporting Diverse Care Home Residents in Engaging with the World. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2011), 1757–1766.

[21] Gaver, W.W., Bowers, J., Boucher, A., Gellerson, H., Pennington, S., Schmidt, A., Steed, A., Villars, N. and Walker, B. 2004. The Drift Table: Designing for Ludic Engagement. *CHI '04 Extended Abstracts on Human Factors in Computing Systems* (New York, NY, USA, 2004), 885–900.

[22] Güldenpfennig, F., Ganhör, R. and Fitzpatrick, G. 2017. How to Look at Two-sided Photos?: Exploring Novel Perspectives on Digital Images. *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services* (New York, NY, USA, 2017), 91:1–91:8.

[23] Gulotta, R., Sciuto, A., Kelliher, A. and Forlizzi, J. 2015. Curatorial Agents: How Systems Shape Our Understanding of Personal and Familial Digital

Information. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (New York, NY, USA, 2015), 3453–3462.

[24] Hallnäs, L. and Redström, J. 2001. Slow Technology – Designing for Reflection. *Personal Ubiquitous Comput.* 5, 3 (Jan. 2001), 201–212. DOI:https://doi.org/10.1007/PL00000019.

[25] Hawkins, D., Neustaedter, C. and Procyk, J. 2015. Postulater: the design and evaluation of a time-delayed media sharing system. *Proceedings of the 41st Graphics Interface Conference* (2015), 249–256.

[26] Helm, S., Ligon, V., Stovall, T. and Riper, S. 2018. Consumer interpretations of digital ownership in the book market. *Electronic Markets*. 28, 2 (2018), 177–189. DOI:https://doi.org/10.1007/s12525-018-0293-6.

[27] Hermans, L., Broekhuijsen, M. and Markopoulos, P. 2017. Memora: A Design for Teenagers to Connect Virtual and Physical Possessions. *Proceedings of the European Conference on Cognitive Ergonomics 2017* (New York, NY, USA, 2017), 121–128.

[28] Herron, D., Moncur, W. and van den Hoven, E. 2017. Digital Decoupling and Disentangling: Towards Design for Romantic Break Up. *Proceedings of the 2017 Conference on Designing Interactive Systems* (New York, NY, USA, 2017), 1175–1185.

[29] Herron, D., Moncur, W. and van den Hoven, E. 2016. Digital Possessions After a Romantic Break Up. *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (New York, NY, USA, 2016), 36:1–36:10.

[30] Hilliges, O. and Kirk, D.S. 2009. Getting sidetracked: display design and occasioning photo-talk with the photohelix. (Apr. 2009), 1733–1736.

[31] Huang, C.-C. and Stolterman, E. 2011. Temporality in Interaction Design. *Proceedings of the 2011 Conference on Designing Pleasurable Products and Interfaces* (New York, NY, USA, 2011), 62:1–62:8.

[32] Jansen, M., Hoven, E. and Frohlich, D. 2014. Pearl: Living Media Enabled by Interactive Photo Projection. *Personal Ubiquitous Comput.* 18, 5 (Jun. 2014), 1259–1275. DOI:https://doi.org/10.1007/s00779-013-0691-x.

[33] Jarvis, N., Cameron, D. and Boucher, A. 2012. Attention to Detail: Annotations of a Design Process. *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design* (New York, NY, USA, 2012), 11–20.

[34] Kirk, D., Sellen, A., Rother, C. and Wood, K. 2006. Understanding Photowork. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2006), 761–770.

[35] Leong, T.W., Vetere, F. and Howard, S. 2006. Randomness As a Resource for Design. *Proceedings of the 6th Conference on Designing Interactive Systems* (New York, NY, USA, 2006), 132–139.

[36] Leong, T.W., Vetere, F. and Howard, S. 2005. The Serendipity Shuffle. *Proceedings of the 17th Australia Conference on Computer-Human Interaction: Citizens Online: Considerations for Today and the Future* (Narrabundah, Australia, Australia, 2005), 1–4.

[37] Lindley, S.E. 2015. Making Time. *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing* (New York, NY, USA, 2015), 1442–1452.

[38] Luxon, A.M., Hamilton, C.E., Bates, S. and Chasson, G.S. 2019. Pinning our possessions: Associations between digital hoarding and symptoms of hoarding disorder. *Journal of Obsessive-Compulsive and Related Disorders*. 21, (2019), 60–68. DOI:https://doi.org/10.1016/j.jocrd.2018.12.007.

[39] Mazé, R. and Redström, J. 2005. Form and the computational object. *Digital Creativity*. 16, 1 (Jan. 2005), 7–18. DOI:https://doi.org/10.1080/14626260500147736.

[40] Mendels, P., Frens, J. and Overbeeke, K. 2011. Freed: A System for Creating Multiple Views of a Digital Collection During the Design Process. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2011), 1481–1490.

[41] Mols, I., van den Hoven, E. and Eggen, B. 2017. Balance, Cogito and Dott: Exploring Media Modalities for Everyday-life Reflection. *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (New York, NY, USA, 2017), 427–433.

[42] Nelson, H.G. and Stolterman, E. 2003. *Design Way: Intentional Change in an Unpredictable World - Foundations and Fundamentals of Design Competence*. Educational Technology Publications.

[43] Odom, W. and Duel, T. 2018. On the Design of OLO Radio: Investigating Metadata As a Design Material. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2018), 104:1–104:9.

[44] Odom, W., Selby, M., Sellen, A., Kirk, D., Banks, R. and Regan, T. 2012. Photobox: On the Design of a Slow Technology. *Proceedings of the Designing Interactive Systems Conference* (New York, NY, USA, 2012), 665–668.

[45] Odom, W., Zimmerman, J. and Forlizzi, J. 2014. Placelessness, Spacelessness, and Formlessness: Experiential Qualities of Virtual Possessions. *Proceedings of the 2014 Conference on Designing Interactive Systems* (New York, NY, USA, 2014), 985–994.

[46] Odom, W.T., Sellen, A.J., Banks, R., Kirk, D.S., Regan, T., Selby, M., Forlizzi, J.L. and Zimmerman, J. 2014. Designing for Slowness, Anticipation and Re-visitation: A Long Term Field Study of the Photobox. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2014), 1961–1970.

[47] Ozenc, F.K., Kim, M., Zimmerman, J., Oney, S. and Myers, B. 2010. How to Support Designers in Getting

Hold of the Immaterial Material of Software. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2010), 2513–2522.

[48] Peesapati, S.T., Schwanda, V., Schultz, J., Lepage, M., Jeong, S. and Cosley, D. 2010. Pensieve: Supporting Everyday Reminiscence. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2010), 2027–2036.

[49] People will take 1.2 trillion digital photos this year: 2018. *http://www.businessinsider.com/12-trillion-photos-to-be-taken-in-2017-thanks-to-smartphones-chart-2017-8*.

[50] Pierce, J. and Paulos, E. 2015. Making Multiple Uses of the Obscura 1C Digital Camera: Reflecting on the Design, Production, Packaging and Distribution of a Counterfunctional Device. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (New York, NY, USA, 2015), 2103–2112.

[51] Pschetz, L. 2015. Isn't It Time to Change the Way We Think About Time? *interactions*. 22, 5 (Aug. 2015), 58–61. DOI:https://doi.org/10.1145/2809502.

[52] Sas, C. and Whittaker, S. 2013. Design for Forgetting: Disposing of Digital Possessions After a Breakup. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2013), 1823–1832.

[53] Sas, C., Whittaker, S. and Zimmerman, J. 2016. Design for Rituals of Letting Go: An Embodiment Perspective on Disposal Practices Informed by Grief Therapy. *ACM Trans. Comput.-Hum. Interact.* 23, 4 (Aug. 2016), 21:1–21:37. DOI:https://doi.org/10.1145/2926714.

[54] Schon, D.A. 1992. Designing as reflective conversation with the materials of a design situation. *Research in Engineering Design*. 3, 3 (Sep. 1992), 131–147. DOI:https://doi.org/10.1007/BF01580516.

[55] Schwanda Sosik, V., Zhao, X. and Cosley, D. 2012. See Friendship, Sort of: How Conversation and Digital Traces Might Support Reflection on Friendships. *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work* (New York, NY, USA, 2012), 1145–1154.

[56] Selby, M. and Kirk, D. 2015. Experiential manufacturing: The earthquake shelf. *Proc. of RTD 2015 Conference on Research Through Design* (2015).

[57] Sengers, P., Boehner, K., David, S. and Kaye, J. 2005. Reflective design. *Proceedings of the 4th decennial conference on Critical computing: between sense and sensibility* (2005), 49–58.

[58] Stolterman, E. and Pierce, J. 2012. Design Tools in Practice: Studying the Designer-tool Relationship in Interaction Design. *Proceedings of the Designing Interactive Systems Conference* (New York, NY, USA, 2012), 25–28.

[59] Stolterman, E. and Wiberg, M. 2010. Concept-Driven Interaction Design Research. *Human–Computer Interaction*. 25, 2 (May 2010), 95–118.

[60] Tsai, W.-C., Chen, A.Y.S., Hsu, S.-Y. and Liang, R.-H. 2015. CrescendoMessage: interacting with slow messaging. *Proceedings of the 2015 International Association of Societies of Design Research Conference (IASDR'15)* (2015).

[61] Tsai, W.-C., Wang, P.-H., Lee, H.-C., Liang, R.-H. and Hsu, J. 2014. The Reflexive Printer: Toward Making Sense of Perceived Drawbacks in Technology-mediated Reminiscence. *Proceedings of the 2014 Conference on Designing Interactive Systems* (New York, NY, USA, 2014), 995–1004.

[62] Tsaknaki, V., Cohn, M., Boer, L., Fernaeus, Y. and Vallgarda, A. 2016. Things Fall Apart: Unpacking the Temporalities of Impermanence for HCI. *Proceedings of the 9th Nordic Conference on Human-Computer Interaction* (New York, NY, USA, 2016), 141:1–141:3.

[63] Tulving, E. 1985. Memory and consciousness. *Canadian Psychology/Psychologie canadienne*. 26, 1 (1985), 1–12. DOI:https://doi.org/10.1037/h0080017.

[64] Tulving Endel, Le Voi M. E., Routh D. A., Loftus Elizabeth and Broadbent Donald Eric 1983. Ecphoric processes in episodic memory. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*. 302, 1110 (Aug. 1983), 361–371. DOI:https://doi.org/10.1098/rstb.1983.0060.

[65] Uriu, D., Odom, W., Lai, M.-K., Taoka, S. and Inami, M. 2018. SenseCenser: An Interactive Device for Sensing Incense Smoke & Supporting Memorialization Rituals in Japan. *Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems* (New York, NY, USA, 2018), 315–318.

[66] Uriu, D. and Okude, N. 2010. ThanatoFenestra: Photographic Family Altar Supporting a Ritual to Pray for the Deceased. *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (New York, NY, USA, 2010), 422–425.

[67] Uriu, D., Shiratori, N., Hashimoto, S., Ishibashi, S. and Okude, N. 2009. CaraClock: An Interactive Photo Viewer Designed for Family Memories. *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (New York, NY, USA, 2009), 3205–3210.

[68] Vallgarda, A. 2014. Giving Form to Computational Things: Developing a Practice of Interaction Design. *Personal Ubiquitous Comput.* 18, 3 (Mar. 2014), 577–592. DOI:https://doi.org/10.1007/s00779-013-0685-8.

[69] Vallgarda, A., Winther, M., Mørch, N. and Vizer, E.E. 2015. Temporal form in interaction design. *International Journal of Design*. 9, 3 (2015).

[70] Whittaker, S., Bergman, O. and Clough, P. 2010. Easy on That Trigger Dad: A Study of Long Term Family Photo Retrieval. *Personal Ubiquitous Comput.* 14, 1

(Jan. 2010), 31–43. DOI:https://doi.org/10.1007/s00779-009-0218-7.

[71] Williamson, J. and Brown, L.M. 2008. Flutter: Directed Random Browsing of Photo Collections with a Tangible Interface. *Proceedings of the 7th ACM Conference on Designing Interactive Systems* (New York, NY, USA, 2008), 147–155.

[72] Zimmerman, J., Forlizzi, J. and Evenson, S. 2007. Research Through Design As a Method for Interaction Design Research in HCI. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York, NY, USA, 2007), 493–502.