ChronoTape: Tangible Timelines For Family History

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ABSTRACT
An explosion in the availability of online records has led to surging interest in genealogy. In this paper we explore the present state of genealogical practice, with a particular focus on how the process of research is recorded and later accessed by other researchers. We then present our response, ChronoTape, a novel tangible interface for supporting family history research. The ChronoTape is an example of a temporal tangible interface, an interface designed to enable the tangible representation and control of time. We use the ChronoTape to interrogate the value relationships between physical and digital materials, personal and professional practices, and the ways that records are produced, maintained and ultimately inherited. In contrast to designs that support existing genealogical practice, ChronoTape captures and embeds traces of the researcher within the document of their own research, in three ways: (i) it ensures physical traces of digital research; (ii) it generates personal material around the use of impersonal genealogical data; (iii) it allows for graceful degradation of both its physical and digital components in order to deliberately accommodate the passage of information into the future.

Author Keywords
Temporal Tangible User Interfaces, Genealogy, Personalisation, Inheritance.

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces—*D.2.2, H.1.2, I.3.3*

General Terms
Design, Theory, Human Factors.

> *"Fewer and fewer Americans possess objects that have a patina, old furniture, grandparents pots and pans, the used things, warm with generations of human touch, essential to a human landscape. Instead, we have our paper phantoms, transistorized landscapes. A featherweight portable museum."* Susan Sontag, 1973

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INTRODUCTION
As part of the PATINA project [8] we have been studying research practices, and have become interested in genealogy as an example of a widespread research activity conducted by both a cross-section of amateur enthusiasts, and a professional industry based around inheritance, publishing and academic history. The past decade has seen an extraordinary surge in interest around genealogy, driven to a large degree by the availability of historical archives and databases through the internet. However, with the introduction of computer databases and online research tools, genealogical research has become increasingly virtualised and detached from physical materials. Our particular interest is in understanding how new technologies might support personal research, and to understand how these technologies support or undermine the institutions that have traditionally controlled and sustained research materials. The use of online tools has provided numerous benefits, especially through access to sources and opportunities for collaboration. However, many of the subtle interactions between researcher and physical materials have been lost.

In this paper we briefly explore the current state of genealogy research practice, with an emphasis on the impact of emerging internet-accessible historical records. We then discuss how the demands of creating personal, rich family histories produced for future generations compete with the demands of recording principled and accurate genealogical data, that can be shared and reused by researchers of related family trees. We explore the resulting tensions that manifest, focusing on whether the researcher's personal contribution to the research should be valued alongside their findings.

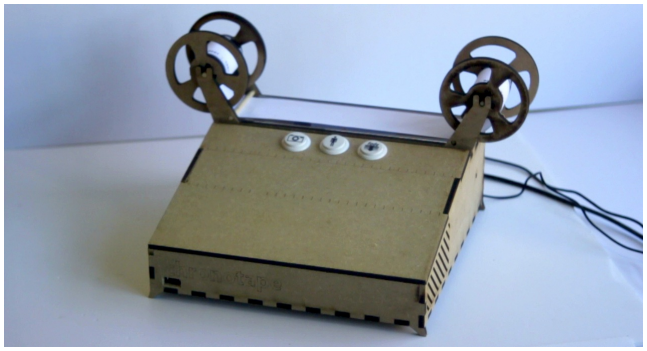

Figure 1. The ChronoTape reader, loaded with a spool of ChronoTape.

Our design response to address this imbalance is ChronoTape, a tangible user interface based around the use of pa-

per timelines. ChronoTape complements online genealogy tools, which excel at constructing a searchable and reusable family tree, with a tangible method of building a family history. ChronoTape can be used on a ChronoTape reader (fig.1), a temporal tangible interface that supports and reveals the valuable personal production of family history research, capturing individual annotations in a tangible form. In contrast to designs that support existing genealogical practice, ChronoTape captures and embeds traces of the family historian within the document of their own research. In the later stages of the paper we discuss how ChronoTape adopts three design principles to support this goal which might be applied to a range of tangible interfaces to support personal research: firstly, it ensures physical traces of digital research; secondly it generates bespoke personal material around the use of reusable genealogical data; and thirdly it allows for graceful degradation of physical and digital aspects in order to deliberately accommodate the passage of information into the future. In order to understand why such a response is required, the following section reviews the current state of family history research and practice.

OVERVIEW OF CURRENT GENEALOGY

Family history is a popular domain of research conducted for personal rather than purely academic or professional purposes. Family history is taken no less seriously or diligently than professional genealogical research, however, professional genealogy is principally concerned with accuracy of relationships and is typically conducted for inheritance purposes, whereas family history is more broad and interested in telling the story of the individuals, a process more akin to biography. However, family history does present an excellent example of 'citizen research', revealing personal motivations for research including the 'thrill of the hunt', connecting with family members and self discovery [9].

In the relatively recent past, archival records were closely guarded and preserved through institutional controls in libraries, museums and government offices by experts, and typically for experts whether genealogists, academic historians, legal researchers or other professionals who needed access to these texts. In contrast, online databases provide searchable civil, ecclesiastical, literary, military, newsworthy and many other forms of historical record, lowering the barriers to begin researching family history. As a result, the traditional techniques of genealogy research have had to rapidly change to accommodate emerging practices of family historians, as well as the sheer increase in volume of requests for access to, and copies of, source material discovered through the Web. These traditional techniques, or 'rules of genealogy', include a range of informal rules of thumb such as: always manually documenting sources in sufficient detail such that future researchers could follow the trajectory of an argument; always checking digital source material you use, whether digitised copies or references in secondary records, against physical originals on the Web to verify transcriptions are accurate; and ensuring that no related material which has been professionally collated and assembled by archivists is missed by viewing a single record through the isolation of online search results. When considering the advice given for genealogy, it is notable that this institutional approach is very much biased to value the official over the personal. Consider this extract from an advice leaflet produced by the Society of Genealogists [21]:

> *Your researches can save others, now or in the future generations, a great deal of time, but only if they have access to your papers, can find their way through them, and can interpret your notes. So:*
>
> 1. ***Avoid personal abbreviations and hieroglyphics.***
> 2. ***Keep papers anchored in files in an intelligible order**, preferably with your most up to date pedigree on top and supporting transcripts, extracts, letters, etc. behind.*
> 3. ***Deposit a copy of your pedigree in the Society's Library** as soon as it is reasonably complete and you have turned to another line.*
> 4. ***Instruct your Executors on the disposal of your files.** The society's Library is glad to receive files (kept as in para 26, on single surnames and transcripts or extracts for single surnames and/or complete for specified dates or places). Random extracts are of little value.*

This process is designed to make it as simple as possible to institutionalise data with minimal work, and remove the researcher's personal fingerprint from the process, making the information relevant to anyone rather than interesting for only the researcher's descendants or family members. The approach is also at odds with stated reasons for getting interested in family history: mystery-solving, the importance of honoring ancestors, and the goal of leaving a legacy for the benefit of future generations [9]. This approach precludes the researcher featuring in the story that they create, despite the fact that, overwhelmingly and as with any other form of biography, a family history is substantially about the teller as much as it is about the story.

The process of writing up family history from a family tree can be problematic given the focus of many online tools is the growth of the tree rather than using the tree to form the basis of a history. The process of learning how to convert a tree into a history has been traditionally supported within institutions such as the records office, also aiding with contextualising the research and making it applicable to a wider audience. Local historians provide an example of how the results of family history research can be woven into a broader history that can be relevant to many people beyond the scope of the original research.

While professional circles have often believed such working practices are often under-implemented in family history, it is clear that institutions with an interest in genealogy believe their control over genealogical procedures and materials is greatly eroding in the face of widespread accessibility over the Web. These tensions also manifest themselves for individual family historians because a key motivator for genealogists is sharing; with their children and their descendants, with living close family members, and to make contact with distant family members through shared research interests. The tension between these audiences; the personal versus the institutional; the community versus the family; structural completeness versus local texture; each finds interest in different aspects of research. Thus, there are intellectual and personal outcomes that vie for attention. These tensions are manifested in and further exacerbated by online genealogy. The simplicity of obtaining information and growing the family tree as an end in itself contrasts with the traditional advice of genealogy—to refer back to physical sources, check and verify materials and take meticulous

notes. As the ability to connect together ancestors sharpens, the ability to produce an account of the rich tapestry of family life fades.

Critically, one of the most common reasons that makes individuals get involved in genealogy is an unexpected discovery that piqued their curiosity, for example a diary, an old photo album or a collection of letters [9]. Indeed, in contrast to the worked-up information that can be easily searched and classified which is advocated in the official texts, personal discovery is often the spark for interest in family history. However, there is limited recognition within institutional genealogy of the place of the genealogist in the story, or the need to capture and produce outcomes of the essentially intangible work into some form which itself might in turn pique curiosity. In short, and particularly in the light of developments in digital genealogy, we suggest that to fulfil the family historian's desire to leave a legacy that there is a need for a bridge between intangible genealogical outcomes and tangible family heritage and inheritance. Whatever the relative stability and merits of internet archiving may be, it is clear that the *nachlass*, or research legacy, of a family historian is becoming increasingly digital. Yet the personal discoveries that often inspired them to take an interest in family history are driven by the tangible ephemera that is so difficult to recreate when content and form are separated, because the patina formed around the object of presentation is disconnected and discarded while its content lives on [13]. We suggest that reconnecting to that significance through tangible artefacts, which can be shared, inherited and valued, will place the family historian back into the centre of the ongoing history of the family, and help future generations to walk in their footsteps. This requires a bridge between the structure of the genealogist and the physical ephemera of the process of family history research. In the following sections we present ChronoTape, a system which we have developed to provide such a bridge.

RELATED WORK

As people amass increasing volumes of digital information, particularly though data rich activities such as life logging, there has been renewed interest in understanding home archiving practices and why people choose to keep or throw away sentimental artefacts (both physical and digital) [1, 12, 17]. This is also increasingly the case with the inheritance of digital data [16], and the use of 'digital wills' in determining how data is passed on. A number of projects have explored the design space of 'technology heirlooms' [13], creating objects that are designed to carry ephemeral digital information into the future. A focus in a number of these projects is the use of a valued object that acts as a sturdy vessel to contain the more transitory digital information. Nonetheless there is growing emphasis on digital data as a shareable and increasingly permanent feature of our lives, and indeed digital genealogy in particular has been an incredible success in terms of sharing data, because there has been a very well developed and accepted data format, GEDCOM (GEnealogical Data COMmunication), operating since 1984.

Focusing on the two areas of digital and tangible time, this project provides a good example of a temporal tangible user interface (TTUI) [2], the study of how time can be represented and controlled tangibly. The aim of placing this project within the context of TTUIs is to allow time, an abstract and intangible concept, to be manipulated with the ease of a simple physical object. Previous work on the BeatBearing TTUI [3] has provided detailed context for the ChronoTape design. Previous TUIs that have made time tangibly accessible include the Khronos Projector [4], which allows users to push through and reveal multiple layers of a time-lapse video, and many musical sequencer TUIs that allow the tangible placement of notes within time. These projects have shown that making time tangible can provide a simple and intuitive method of interacting with the abstraction and complexity of time-based systems. However, there are many design problems unanswered in these prior projects, including scalability, fidelity, legibility and longevity that we aim to address in the design and study of the ChronoTape.

Examples of how alternative computer interfaces have been used for enhancing historical research include a table-based TUI for supporting art history [6]; the 'Augurscope', a mixed reality interface for revealing a hidden medieval castle [18]; and an augmented reality game for educating the practice of history research around the Battle of Lexington [19]. One common theme amongst these is the counterpoint created between historic materials and present technologies, neglecting to consider how the interface itself ages and moves into the future.

The ChronoTape also follows a range of mixed reality designs which use physical paper to complement digital data. Examples include augmented flight strips, AR storyboards and augmented engineering drawings [15]; books augmented with oral histories delivered by video clips [14]; and the affordances of paper used as a method of control such as in Paper Windows [10]. One of the primary goals of such projects is to take the highly successful and refined technologies of pen and paper and provide them with the capabilities of digital computing. In this case we are drawing principally on the success of paper as an inheritable commodity, which can acquire patina to reflect its age whilst remaining valuable.

CHRONOTAPE DESIGN

The ChronoTape has been developed as a new tool for family tree researchers, allowing them new methods of gathering, interacting with and archiving their research. The ChronoTape design is an example of a Temporal Tangible User Interface (TTUI) [2] which captures 'research patina' and is designed to be legible and useable in existing genealogy settings, for example a typical records office, archive or home office environment. In the following sections we explore the design of ChronoTape according to these properties.

Temporal Tangible Interfaces

We wanted to explore the design properties which would successfully support a TTUI, an interface which makes time tangible. Drawing on this exploration of current genealogy, we suggest three design principles.

Firstly, a tangible interface needs to take seriously the tangibility of research materials into the future by leaving physical traces of research, as well as tangible means to explore the past. Secondly, the requirement to incorporate researchers

within the temporal context of their own research suggests that an interface should leave traces of research in ways which persist and may be discovered by descendants. Thirdly, taking seriously long term inheritance of such information requires that whatever interfaces we design we should allow for the graceful degradation of the strength of links between of physical and digital information so that the passage of information into the future is not dependent on those links.

One of the main aims of the ChronoTape interface is that it allows the researcher to construct a research document that encourages the build-up of personal annotations, recording not only their research material but traces of their research activity. Personal annotations are relevant as an aide-mémoire for the family historian, but also to act as ephemera to spark interest and lines of enquiry for future researchers who would like to 'walk in the footsteps' of the original researcher. The potential readability of the notes after a long period of time is of prime importance if research is to pass from generation to generation. We have concentrated on producing a tangible research document alongside a digital genealogy, because although there is increasing work in the sharing of digital annotations with semantic relevance, a physical object that can be left in a loft or basement can remain discoverable in content, and also acquire material patina that reflect its passage through time and inspire future generations with its historic appearance.

A previous example of a TTUI, the BeatBearing [3], uses ball bearings to represent musical notes and a digital moving line to represent the timeline. ChronoTape takes the opposite approach to the BeatBearing as it features a tangible timeline containing intangible events. The timeline is made physically controllable, allowing the user to manipulate time-based events with the ease of a TUI. This timeline can then persist and be read without special apparatus. We have been inspired in this design by microfilm, which is frequently used to archive genealogical records. Microfilm technology only requires magnification to retrieve information, and thus represents a simple human readable interface. The ChronoTape also represents an 'ideal' tangible representation, allowing the tangible aspect of the interface to be read in the absence of a digital representation. While ChronoTape works independently of digital augmentation, the ChronoTape reader is a bridge between digital, professional genealogy and tangible, personal family history it also provides a mechanism for overlaying a digital family tree onto a physical length of ChronoTape.

A wide variety of frameworks exist for conceptualising TUIs [7], out of these we have primarily referred to the MCRit model [22] during the development of the ChronoTape due to its simple breakdown of the TUI into several parts. Discussion of the Model, Control and Representation (intangible/tangible) framework in relation to the ChronoTape has helped to focus design discussions around the important tangible interface design decisions. An example being the discussion around the physicality of the representation, and deciding on the balance between physical representation and digital representation of information. The aim with the ChronoTape was to try and keep the two types of representation closely linked and almost indistinguishable while in use, but easily separable in the future.

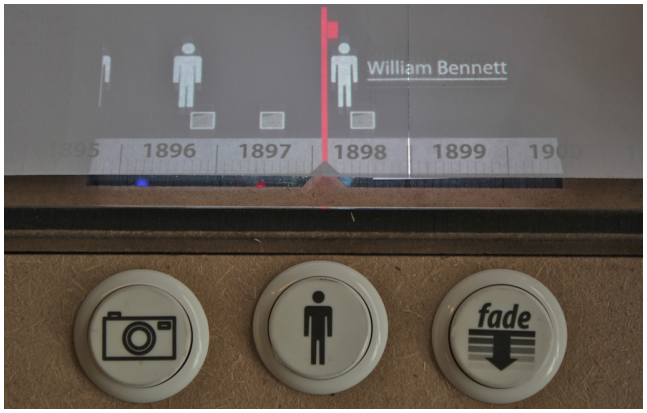

Figure 2. ChronoTape close-up. The left button adds a photograph, the middle button adds a person icon and the right-hand button fades out digital items on the tape. The red line indicates the current position on the tape.

Design Influences

Our design influences, given in overview below, highlight how we have drawn inspiration from technologies that may be familiar to family tree researchers.

Writing slope. The aesthetic of the device is intended to resemble a writing slope in external appearance, and to encourage placement of research documents on the slope of the device. As with a writing slope, the reader could fold into a portable briefcase.

Reel-to-reel tape decks, both in appearance and operation, also as an interaction metaphor. Microfilm (a primary method of research at records offices). Cine-film projectors. Sewing machines (loading the thread, maintaining smooth operation through various adjustments to thread tension).

Digital controls. While the tangible aspects of ChronoTape are nuanced, we decided to make aspects of its operation which relate to digital genealogy as immediate and digital as possible. We used arcade game controls to achieve this aim and create a playful style of interaction for input of digital information, with the buttons providing typical digital operations that might be associated with genealogy, such as digitisation of physical materials, or to create notes of ancestors. We also provide a keyboard to enter digital text at specific times on the tape. The aesthetic of these digital controls emphasises the difference between tangible annotations and digital structures.

Paper tape. Scrolls (linear and continuous display of information). Photographic slides (tangible tiles). Pencil (pencils are the only writing implement allowed in records offices).

THE CHRONOTAPE SYSTEM

The ChronoTape reader (fig.1) supports a number of techniques for writing information on to the ChronoTape. Both the digital functions and tangible operations are described below.

Digital Functions

Digital information can be added to the ChronoTape through the use of the three arcade buttons on the reader (fig.2) and the use of a wireless keyboard. Each of the digital operations is associated with an individual sound effect that gives feedback on the operation. A red line running across the centre

of the tape is the 'record-head', indicating where the buttons will place information. The digital operations include:
Add Person. A person icon can be added at any point on the tape by pressing the person icon button. This function is deliberately ambiguous and can be used in many situations from the well-defined, such as marking the date of birth or death, to the more informal, such as marking an event that happened to a person.
Add Text Note. A text note can be entered at any point on the tape by simply typing a note on an associated wireless keyboard. As a note is being typed it is shown in red and is not attached to the timeline. Whilst in this 'unattached' state, the text can also be moved vertically up or down the timeline by using the arrow keys on the keyboard. When the user presses the return key, the text is 'stamped' to the timeline and becomes white. Once the text has been stamped to the tape, the text cannot be edited on the reader. The aim is to encourage the user to erase and rewrite the text in the same manner as using a pencil and eraser.
Add Photograph. A photograph of the writing slope can be taken in order to capture source material that is being used to populate the timeline. The photographic ability of the ChronoTape is for note-taking although it could also be used to digitise original documents or photographs in context with their creation or use. Photographs can also be taken of objects on the slope to illustrate the timeline.
Fade. This button fades any digital information that is currently underneath the red selection line, and was designed to have the interaction metaphor of rubbing out pencil marks with an eraser. The button needs to pressed multiple times to fade the information, each time slightly fading the underlying information. The user is prevented from completely fading the information out, so the most faded items remain just visible, allowing a digital patina of faded notes to accumulate over time.

Figure 3. ChronoTape spools, used for storage and timeline control.

Tangible Operations

ChronoTape has been designed to make use of papers key affordances of tangibility, spatial flexibility, tailorability and manipulability [20]. As such, the physical handling of ChronoTape is open to improvisation, however we list the standard tangible operations below:
Navigation. When placed on the reader, the spools of ChronoTape (fig.3) are used to navigate through the tape by winding the tape from one spool to the other.
Pencil, Pen and Eraser. The timeline has been designed to allow the use of pens and pencils on its surface in order to quickly capture notes. The aim is to create interplay between the digital and physical notes, with the user quickly

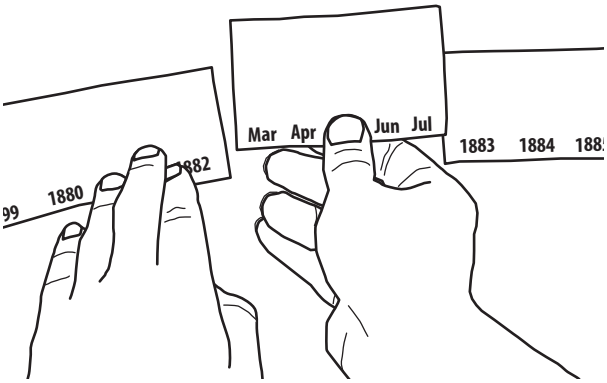

Figure 4. Splicing a section of month-tape into a year-tape.

swapping between the different types of taking notes depending on the context, level of certainty and type of information. The use of pencil reflects our goal of producing an ephemeral tangible object, and also aligns with the typical requirement of using pencil rather than pen in institutional settings such as the records office.
Splicing Tape. The final operation involves cutting and splicing different lengths of tape together to edit the timeline. This allows the years to be ordered non-linearly, and also allows the possibility of varying temporal resolution against a linear amount of tape, for example by inserting a section of 'month tape' into a section of 'year tape' to capture events at a higher level of detail (fig.4). Another possibility is to edit tape to allow the telling of stories which may jump back and forth in time. In order to encourage the use of tape sections we have developed an analogue of the photographic slide frame to hold sections of tape, allowing important segments of tape to be easily manipulated and rearranged in the style of a tile-based TUI (fig.5).

Figure 5. Using slide frames to turn sections of tape into tangible tiles.

Construction and Hardware

The ChronoTape reader is constructed from laser-cut wood, allowing the interface to be readily reproduced. The software runs on a laptop which is connected to a pico-projector placed under the writing slope of the ChronoTape reader. A mirror is placed in front of the projector at an angle of 45° to reflect the projection onto the underside of the tape. Battery operation of the laptop and projector allow for use away from a power source for approximately two hours.

Tracking the Tape

The ChronoTape uses the reacTIVision fiducial marker system [11] to track the position of the tape. A line of the fiducial markers is printed on the underside of the tape (fig.6).

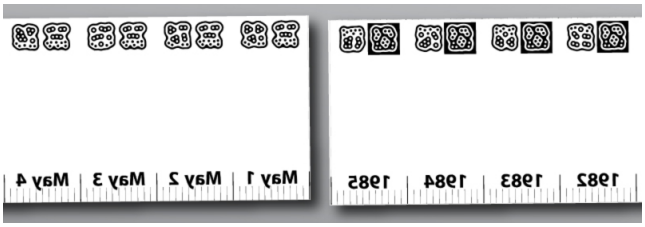

Figure 6. Day-tape on left and Year-tape on right. The text is reflected so that it can be read from the opposite side of the tape.

The markers are viewed by a webcam aligned with the projector in the ChronoTape reader. An LED is used to provide flicker-free illumination of the fiducial markers. This light also back-illuminates the tape allowing the year numbers to be clearly seen from the front; in absence of the reader other sources of light can be used to read the tape (fig.7).

Tape movements of less than half a millimeter can be sensed due to the scale between the webcam and fiducial markers. The webcam captures a 640×480px image of an area measuring approximately 120×60mm, so moving the tape 1mm equates to an on-screen displacement of approximately 5 pixels. The year-tape uses a scale of 24mm per year, with 2mm per month. The day-tape uses a scale of 24mm per day with 1mm per hour. These scales were chosen so that the smallest unit could be easily measured with a ruler.

Two fiducial markers are used to encode each date. For day-tape the first marker is the month and the second is the day and for year-tape the first is the century, and the second is the year within that century. The rotation of each marker is used to determine between the two types of tape. The tape does not identify individual users, only providing access to the timeline data held on a USB stick. This means it is possible for a user to overlay another person's digital information on their own ChronoTape, simply by loading another persons data while their own tape is still on the reader.

The tape is printed in sections on A4 paper, cut into strips and then joined with adhesive-tape. This approach has been chosen over a custom printing solution, such as a receipt printer, for two reasons. Firstly, the ability to print and construct a timeline from A4 lengths allows a researcher to print off more timeline strips without requiring special equipment. Secondly, the preparation of a length of tape requires an investment of time and energy, encouraging the researcher to value their home-made ChronoTape more highly than a manufactured tape. The concept of printing a tangible user interface on a home printer, with only the addition of a computer and webcam has been explored in the D-Touch system [5]. Similar functionality has been developed for the ChronoTape, allowing the researcher to use their own computer to display timeline information by holding the ChronoTape up to their computer's webcam. This method retains the basic tangible interaction, trading off the more advanced tangible interaction of the ChronoTape reader for increased accessibility. This method should be considered a secondary, or backup, method of viewing ChronoTape information, with the reader still providing the primary method of interaction.

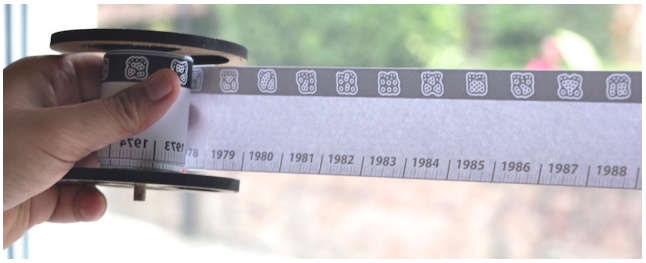

Figure 7. Viewing the years on the ChronoTape by holding up to a window. The years are printed in reverse on the back of the tape to help blend the printed material with the digital projection.

Software & Digital Storage

The ChronoTape software is written in Processing, a free and cross-platform language, making the ChronoTape source code easily accessible and modifiable. The Reactivision tracker application runs in the background, sending the markers' position and ID to the software. Ableton Live is used for the audio, with sound effects triggered by MIDI messages.

The digital notes on the timeline are recorded in a simple human-readable file structure. All data recorded onto the timeline is saved in a single folder on a USB stick that slots into the front of the ChronoTape. When a new note is entered on the ChronoTape, a corresponding text file (and jpeg file for photograph notes) is created within the date-based folder hierarchy. The name of the text file incorporates the date of the note so that the operating system's file browser can be used to sort the data into chronological order. Inside each note file a header is used to store information necessary for the ChronoTape's operation, including the exact position on the tape, the current 'fade' value and the vertical position on the tape. Each of these values is written to the text file in an easily understandable way (fig.8).

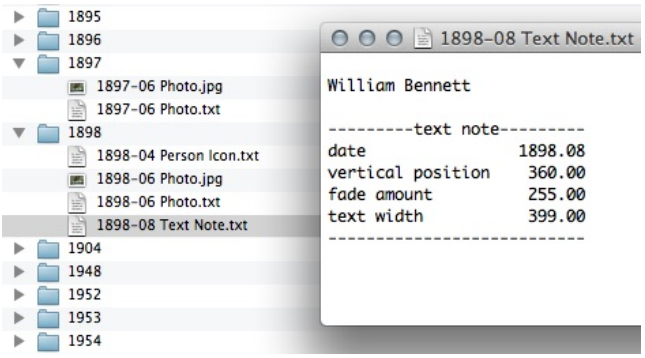

Figure 8. The ChronoTape saves all data in a human-readable (and writeable) folder structure. The folder structure and text note corresponds with the ChronoTape shown in figure 2.

This simple form of digital storage using a folder and file structure allows the data stored on the tape to be both human-readable and human-writable. New notes and photographs can be easily added to the ChronoTape by simply dragging and dropping new files into the folder structure. Modifications to notes can be easily made by adjusting the values in the text file, for instance changing the date of the note, changing the text in a note, or even 'unfading' the note by

increasing the fade value. The digital storage has been designed in this manner to increase the long-term persistence of the data. The aim is also to increase the user's confidence that they can edit and view the data directly without additional software. The decision not to allow editing of existing notes via the ChronoTape reader was made in order to emphasise the use of the tape as a notebook, where old notes are read and perhaps written on but are not usually edited.

TESTING

Informal user testing has been undertaken throughout the development of the ChronoTape, from early cardboard sketches and prototypes through to the current system. Tests have ranged from quick assessments of particular aspects to longer trials where a whole section of family tree has been explored.

Participants were asked to bring research documents to work with alongside the ChronoTape reader (fig.9). They were given the choice of telling a story about a part of their family tree they were currently working on, using it to record a favourite story about a part of their tree, making notes on the ChronoTape as they proceeded, or simply using the ChronoTape to make notes on their immediate lineage. Observations made from these tests are discussed in the following section.

Figure 9. Using a pencil to write notes from original source material.

DISCUSSION

During testing we noticed a number of features which could enhance the ChronoTape interface. Unlike a traditional family tree structure the ChronoTape makes time linear and therefore collapses multiple branches of a family tree into a single thread. We therefore expected a ChronoTape might become very crowded with physical and digital annotations as multiple stories overlapped. In fact we were surprised that there was not as much overcrowding of the tape as we expected. Although there might be temptation to produce a bifurcating tangible structure to support tree-like navigation, in this case 'serialising' a tree into a timeline had a number of benefits.

The use of linear time acts as a frame of reference for re-understanding the sequence of events; the testing revealed that translating from a tree structure to a linear temporal frame of reference sometimes resulted in surprising layouts for researchers of their own tree. This may be because family historians often encounter events of interest in isolation and build up a topological structure from individual records. The ChronoTape presents both the events and the empty space between them equally, with the result that the gaps in which 'nothing' occurs become more noticeable as users have to make an effort to scroll through them, in turn leading our testers to consider what was happening in their ancestors' lives during these blank periods. Furthermore the temporal anchoring of the ChronoTape allowed participants to further reflect on the broader narrative history, such as of the nation or local area, and how it may have affected their ancestors. We therefore suggest that ChronoTape may provide a useful way of bridging between personal and national history, and considering relatives in context. To achieve this requires the import of historical data, such as records of government, location or military history, onto a new roll of ChronoTape, as side-by-side comparisons can be easily made between multiple lengths of tape.

We found that people were typically more inclined to tell stories with the ChronoTape than to use it only as a digital note-taking tool. There was typically lots of talking around the interface, with the reader being used to support communication with others. An advanced system could include a microphone in order to record conversations directly onto the ChronoTape. Again, the simplicity of a printed timeline helped communication to emerge, because the passage of time and history are more easily understood and shared by onlookers than generational sequences that are personal to a researcher's family.

Finally, we reflect on the use of physical and digital annotations. The possibility of annotating ChronoTape both physically with pencil and digitally with keyboard leaves open to the researcher which forms of trace they wish to leave. In future work we plan to formally study the selections that are made to differentiate physical and digital markings made over the tape. Informally it is clear that digital annotations are restricted to keyboard characters and can be searched and used as links into information to allow it to be discovered or re-discovered, while physical marks conveyed the personality and emotional responses to research stories, and are freeform. Early testing leads us to believe that people are sufficiently aware of the capabilities of digital text that they will use digital annotations in a similar way to search terms or hash tags. Particularly as data which must be designed in order to be re-discovered, for example they might represent unique facts of the story (names, dates, places). Physical markings, on the other hand, convey uncertainty and scribbling, and are used to layer impressions or responses over digital facts.

FUTURE WORK AND CONCLUSIONS

In this paper we have explored the design of temporal tangible interfaces that support personal research. Our work has revealed three key principles which may be used in novel designs that take seriously both temporal tangibles and personal research technologies. The first principle is to encourage the capture of physical traces made during the process of digital research. The second principle is to generate personal material around the use of reusable data. The third principle is to support graceful degradation of both physical

and digital information in order to accommodate the passage of valued research into the future.

In future work we plan to enhance the ChronoTape and reader in a number of ways: loading GEDCOM data and displaying it on the tape; provide in-built cutting and splicing tools on the reader; supporting the use of ChronoTape with nonlinear timescales; a downloadable application to allow researchers without access to a ChronoTape reader to access their digital ChronoTape data; and recording the daily use of the ChronoTape reader on a new length of tape, allowing the researcher to view, reflect upon and annotate their own research activity using the ChronoTape itself.

Throughout this process we will continue to be guided by the principle that as little technology as possible should be necessary to recover information from a length of ChronoTape. Our design 'gracefully degrades' in the complexity of technology required to recover information. The digital data is accessible using off the shelf hardware; the digital data is stored in human readable form and does not require custom software for interpretation; and finally we have steered our design towards the production of ChronoTape which consists principally of personal annotations, that in the absence of any compatible digital system have enough context to remain valuable. The design of physical ChronoTape provides just enough temporal context for the 'facts' that are contextualised by valued personal annotations to be recovered by future generations with a new generation of exciting and challenging research that captures the essence of the past process.

We argue that this progressive independence of technology makes ChronoTape a true example of a temporal-TUI, both in terms of its representation of time as an interesting feature of family history research; and its production of material which can acquire and increase appeal through an accumulated patina. In these designs, it is necessary to take seriously the future trajectory of information just as much as to take an interest in its past.

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