Entangling the Roles of Maker and Interpreter in Interpersonal Data Narratives: Explorations in Yarn and Sound

Mikhaila Friske
Dept. of Information Science
University of Colorado
Boulder, CO, USA
mikhaila.friske@colorado.edu

Jordan Wirfs-Brock
Dept. of Information Science
University of Colorado
Boulder, CO, USA
wirfsbro@colorado.edu

Laura Devendorf
ATLAS Institute &
Dept. of Information Science
University of Colorado
Boulder, CO, USA
laura.devendorf@colorado.edu

ABSTRACT

To explore how materials, data, and humans collaborate to produce physical data representations, we created a series of artefacts from personal data we collected (about commuting, forgetting, and busy-ness) in different media—yarn and sound. We exchanged these artefacts without providing guidelines for how to interpret them in order to study where the boundary between maker and interpreter emerges. Through creating hand-crafted physicalizations and sonifications, we present three themes on making personal data narratives: matching data to the materials (and vice versa), accepting the materials' will to co-author, and negotiating between the experience of the data and data of the experience. In exchanging the artefacts, we explored the role of the interpreter as a re-maker and how multiple narratives can productively co-exist. We conclude with a discussion about how reimagining the roles of maker and interpreter might lead to new interactions with personal data narratives.

Author Keywords

personal informatics; sonification; physicalization; research through design

CCS Concepts

•**Human-centered computing** → *Human computer interaction (HCI);*

INTRODUCTION

Over the past decade, HCI has witnessed a rise in interest in personal informatics and has studied how interactive systems can shape how we understand, perceive, and interact with data about our bodies or environments. In some cases, this data is materialized as screen-based representations; in others, it manifests as aesthetically curious details to physical objects like ceramic cups [14] or 3D printed mementos [55]. Encoded within each of these "data-things" [55] is a narrative of the data collected, a partial record of time and experience.

Inspired by Bennett's idea of *thing power*, which considers materials as living things possessing agency [4], this project studies how and what material forces shape the form and interpretation of data narratives. We ask: *Where do the boundaries between maker and interpreter emerge with data things?* and *Who or what has the authority to interpret narrative and assign meaning to data things?* In addressing these questions, we draw inspiration from a year-long postcard exchange between Giorgia Lupi and Stephanie Posavec documented in the book *Dear Data* [49]. Each week, they exchanged hand-drawn visualizations via post, on an agreed upon topic, in hopes of getting to know each other. *Dear Data* is a *personal documentary* involving an analogue, humanistic, reflective approach of collecting, visualizing, and sharing data, allowing for deep interpersonal connections to form. We find inspiration in how *Dear Data* considers the process of deriving meaning from data as a social act and in the project's slow, reflective process of creating data narratives.

Dear Data's approach to creating personal data narratives motivates our work; however, we depart from it in two key ways: first, instead of drawing, the first and second authors (Mikhaila and Jordan) exchanged narratives of yarn and sound. Second, whereas *Dear Data*'s authors did not have a personal relationship before beginning their project, Mikhaila and Jordan were colleagues, thus we explore the exchange of data things in the context of friendship. Over the course of a few months, Mikhaila and Jordan collected personal data on agreed upon topics (commuting, forgetting, and busy-ness), designed and made artefacts with this personal data, and exchanged the artefacts for interpretation without guidelines for interpreting them. We present the six artefacts created by Mikhaila and Jordan as well as themes that emerged from reflecting on the process of making and exchanging these data narratives: (1) matching data to the material (and vice versa); (2) accepting the materials' will to co-author; (3) contrasting the experience of the data with data of the experience; and (4) embracing the co-existence of multiple narratives. We conclude with a discussion that reinterprets the roles of maker and interpreter

in the production of data narratives. Specifically, we shift from a view of there being one "true" narrative toward multiple narratives equally informing each other and the ongoing understandings of the data. By doing so, we consider how HCI and personal informatics researchers might be able to rethink how diverse materialities can be leveraged to shade the interpretation of data and how data narratives—like memories of an experience—evolve and reform in conversation with others.

RELATED WORK

To situate this research, we first describe the field of personal informatics. Next, we outline work showcasing the authority of data and data representations. Finally, we consider existing work in physicalization and sonification.

Brief History of Personal Informatics

As technology that can collect and transmit data becomes integrated into our daily lives, the field of personal informatics—also known as self-tracking, quantified self, or life logging—has grown. What separates personal informatics from other types of technology-mediated data collection and surveillance is the goal of supporting people in individual or collective reflection, self-knowledge, and self-improvement [46]. Work in personal informatics looks to understand the usage of devices [40], provoke and support reflection [45, 46, 73], and study the interplay between self-tracking technology and culture [13, 50]. Much work in this area focuses around health and wearable fitness trackers [29] and biofeedback [31, 32, 60]. Some work has been critical of the dynamics of control inherent in health tracking. For example, "Vivewell," a speculative design work, highlights how menstrual tracking technology might expose dynamics of power in partner or parent-child relationships [21]. Lupton warns of how self-tracking's emphasis on personal optimization produces a "new individualism" that "involves concentrating on the self to the exclusion of social groups, organisations, or communities" [50].

Evolving from personal informatics, *lived informatics* considers how tracking fits into people's complex lives [20, 59] and *documentary informatics* focuses on tracking of personal information solely for documentation (i.e. to help recollection of a memory and not to change behavior) [18]. In recent years, the field has taken a turn toward a slow, reflective approach exemplified by *Dear Data* [49], a project in which two friends created and exchanged hand-drawn visualizations of deeply personal data. We find inspiration in two elements of *Dear Data*: First, in seeing the process of deriving meaning from data as a social act. Other work in this vein includes "The Connected Shower," where researchers studied housemates who collected and then discussed data on showering activities and found that "intimate data is not intimate per se...but is an interactional outcome" derived from conversation [42]. Second, we are inspired by *Dear Data*'s slow, reflective process of creating visualizations. In addition to the postcards, the book includes meta-reflections on the process of creating them, where Lupi and Posavec discuss the mental and physical labor involved ("I think this is a great idea!! ... F**k! Start over" [49].) Other work has also focused on hand-drawn processes. For example, Ayobi et al.'s work explored bullet journaling to

understand how technology and trackers may be informed by a slow, hand-organized task [2].

Recent HCI work has explicitly engaged *Dear Data*, such as "Data Selfie," which qualitatively captures the values and themes of the postcards through an application for creating personalized visual vocabularies [41]. We hope to extend this work by shifting our attention to the slow, reflective, humanistic approach to the visualizations, which we found to be particularly captivating. Our work looks to keep the humanistic and analogue inspiration of *Dear Data* while extending the medium from 2D visualizations to physicalizations and sonifications. Further, we noted that, while reading *Dear Data*, the painstakingly detailed legends are often just as interesting, and contain as much of a data narrative, as the visualizations themselves. Thus, in this work we explore how data narratives might further evolve (or possibly devolve) *without* this kind of guiding annotation.

The Authority of Data

Personal informatics and other widespread uses of data in society have spawned research that explores the authority of data: Do the insights gained from data (and visualization) hold a special power? And how do they complement other types of insights? One perspective comes from the idea of "data doubles," introduced by Haggerty and Ericson to describe how data collection creates digital versions of humans that can be commodified [27]. These data doubles are not us, but they stand in for us, and often have more authority than we do, as evidenced by the challenges that face people who have erroneously been designated as dead in "authoritative" databases [5]. Lupton, writing about the sociology of self-tracking, notes cases where people "began to trust the digital data over [their] own physical sensations" [50] and warns that relying on data we collect may suppress our natural instincts and intuitions about our own well-being. Further, work in the non-profit sector has shown that the push to be "data-driven," which promised to empower organizations, can disempower them through eroding their expertise [7]. We reference these perspectives not to imply that data is inherently dehumanizing—rather, to suggest that when using data, we need to consider who is using it and how, instead of blindly accepting its authority.

We are inspired by work that takes a different perspective on the role of data and its authority. For example, Gulotta et al.'s "Curatorial Agents" [26] exposes how human-created interpretations and machine-created interpretations of data differ, and points out that these differences can be productive and that misinterpretations (and mis-remembrances) are important phases in how people create and share the narratives of their lives. In "Metadating," researchers held a speed dating event where participants created and exchanged data profiles—some data "accurate" as confirmed by tracking devices, some estimated, some completely fabricated [19]. This shows how data can be a "creative material" with its own "social life" rather than a source of objective truth. Finally, we are also encouraged by Pousman et al.'s work on "Casual Information Visualization," which looks at examples of visualization where the goal is not necessarily to accomplish an analytic task [57]. They question the idea of what an insight even is, writing, "We

take insight to be something complex and heterogeneous, not simplistic or monolithic." In addition to analytic insights—the traditional outputs of visualization—they also identify aware-ness insights, social insights, and reflective insights. We focus on these alternate non-analytic insights in our work.

From Visualization to Physicalization and Sonification
Graphical representations of quantitative data have a long his-tory, from map making to thematic cartography to statistical graphics [22]. Visualizations can be useful in exploring and understanding large datasets [11, 51] and they leverage human perceptual abilities to facilitate gleaning knowledge from data [61, 68, 75]. However, visualizations are just that—visual. Recent works have explored alternative ways of experiencing data through physicalization and sonification, terms that sug-gest involving other senses—touch and hearing. This section expands on these two areas as they relate to the personal data narratives presented in our work.

Jansen et al. defines and describes data physicalization, as something that leverages humans' abilities to process complex, multi-sensory information [38]. Simplified, a physicalization is a physical artefact whose geometric and material proper-ties encode data. The work describes "intermodal perception," an approach that "guarantees cohesive and realistic multisen-sory experiences" because perceptual senses become tightly woven together while inspecting physical objects. Data phys-icalization research focuses on understanding how to design physicalizations [34, 76], tools to support design [67], and applications—education [39], information retrieval [65], and workshopping with data [35]. Physicalizations and tangible representations are especially interesting within the realm of personal informatics as they offer freedom of creativity and mindful reflection [1]. Work on representing personal data in physical forms looks at visualizing device-tracked [14, 36, 60] and self-tracked [55, 69] information. Additionally, personal physical data visualizations can support rich storytelling to an individual or group. For example, Zhu's "My Heart on My Sleeve" dress [6] dynamically changes with entries to her personal digital journal entries—the dress itself invites people to interpret the meaning regardless of whether Zhu reveals what her digital diary said. Physicalization can often push the boundaries of what and how information is represented and how materials can be involved in the storytelling. Our project probes these aspects of storytelling through the per-sonal collection and exchanges of data, questioning their role as "authors" among a variety of other material affects.

Sonification is the use of non-speech sounds to communicate information [72]: for example, rising and falling home prices sung as opera [24]. This type of sonification, parameter map-ping, translates a dimension of data into a quality of sound such as pitch. Other techniques include auditory icons, which use sonic metaphors to evoke information being represented (i.e. the sound of rain representing information about water) or earcons, which are "short, structured musical messages" [52] that don't have any predetermined semantic connection to the information they communicate. Sonification typically deals with non-speech sounds, but some techniques explic-itly use verbal language (i.e. spearcons [71]) and there has

been recent work on mixed speech and non-speech displays [28, 44]. Sonification has not experienced the wide adoption that visualization has—an issue that is a subject of ongoing discussion within the community of sonification researchers [53, 54, 66]. One explanation, offered by Cornejo [12], is that sonification researchers—working in a field that requires extensive training and specialized software tools—have not traditionally embraced user-centered design approaches, al-though there have been recent moves in that direction (such as [25, 43, 64, 74]). Another explanation, posed by Roddy and Bridges [58], is that sonification designers have employed an overly computationalist approach, yet "discrete sonic dimen-sions such as timbre, pitch and amplitude have little to do with the listeners' everyday experience of sound." In this work, we engage these challenges by using sonification in an autobio-graphical context and by sketching with found and created sounds, rather than generating algorithmic compositions.

METHODS
To investigate the boundaries and implications of authoring personal data narratives, we chose to explore crafting self-tracked data (through yarn and sound). By creating our phys-icalization and sonifications by-hand—meaning we did not engage algorithmic creation from the data to design our nar-rative intent—we purposefully redistributed authority toward the human and the materials.

We use a paired, autobiographical, research through design approach. First-person methods have increased within HCI, particularly within design [10, 15, 30, 37]. Our approach draws on the tradition of reflective design [62], which en-courages us to bring unconscious elements of our experiences with technology—or, in this case, data—to our conscious awareness. The artefacts we created and exchanged served as *cultural probes* [23] for exploring the relationship between data and narrative meaning. In another sense, they could be thought of as HCI-Amusements, allowing us to exchange and trade experiences as a means of rethinking current trends in physicalization and sonification [15]. Our decision to focus on the narratives embedded in data artefacts is inspired by Gulotta et al.'s work on "Curatorial Agents" [26] which posits that, "it is impossible to separate that information [collected about a person] from the story it tells about that person."

We chose a first-person research method because our research questions required both vulnerability, in creating and sharing the personal artefacts, and a deep understanding of our ma-terials, for when language failed to describe our actions. We (Mikhaila and Jordan) are friends and colleagues, thus this project explores the boundaries of authorship in the context of a preexisting personal relationship. Our mutual familiarity allowed us to feel comfortable taking risks—while tracking, designing, creating, and interpreting the data artefacts—that we may not have taken with a stranger.

An Exchange of Personal Data Narratives
In the following section, we describe the four steps completed to create each artefact: collection of personal data; reflection and design; embedding narrative intent; and discovery of a

Figure 1. Jordan's (non-maker) interpretations: Choosing the green triangle to be the top left, there become two geometrically mirrored sides. The two mirrored sides could be morning and evening commutes. There are different items protruding from the patches (fins at varying angles: "mountains" with "caves" inside). Each of these could be different events that happen on the commute—they heard or saw something. I also notice there are three colors and I think each color could be a way of commuting: bus, car, and walking. Mikhaila's (maker) interpretations: The color of the base denotes whether I drove my car (blue), rode the bus (green), or if the commute was frustrating regardless of transportation (orange). The protruding objects are additional details of the commute (convenience = green, time = blue, and being in a hurry = orange).

narrative. The first three steps were completed autobiographically, though not without influence of the collaboration as our research progressed. The last step was completed by exchanging the artefacts without indication of what information had been embedded other than the topic (commuting, forgetting, and busy-ness). Because the goal was to create personal data narratives, we (Mikhaila and Jordan) not only collected personal information around the chosen topics, but also chose mediums for creation that are personal. Mikhaila chose to crochet or knit because they enjoy the tactile nature of crafting and how it forces them to slow down. Jordan chose to create sonifications because she is an avid listener of audio media, such as podcasts, and is intrigued by how sound must necessarily travel through physical materials, yet is often not perceived as tactile. While we had deep familiarity and experience with our chosen media, we had very little expertise of the others' media. Throughout the research, we refrained from revealing too much about what we were doing to avoid biasing the other person's initial interpretations.

At the beginning the project, we met to decide what topics to explore and to outline the research process. From a list of roughly 15 possible data collection topics—which included inside jokes, media diets, and interactions with animals—we chose three to focus on, each for different reasons: commuting, which we thought would be a relatively straightforward topic with which to troubleshoot our processes; forgetting, which interested us because of the data collection challenge it posed—forgotten items are only known through remembering; and busy-ness, because Mikhaila wanted to reflect on time management and Jordan was interested in contrasting

perceived busy-ness with experienced busy-ness. Each topic took about three to four weeks in total: roughly one week to collect our personal data; two to three weeks to design and make the artefacts; and a week to examine and interpret each other's artefact. In the following section, we explain more about each step of the process.

Collection of Personal Data
For each data topic, we collected personal data on that topic for a week. We did not constrain or define what information should be recorded or how. Independently, we decided the particular details on what information and how we were going to keep track of our data. Therefore, we had to negotiate between what data we could collect on the topic, how we might feasibly collect the data ourselves, and whether we had a preexisting narrative in mind or were discovering a new one. Mikhaila chose to keep all collected information in the same notebook, which was also used to reflect and design the personal data narrative. Jordan chose different data collection strategies for each topic (notes on a smartphone, on paper notecards, and in a digital diary on a laptop). While Jordan started by collecting some data with voice memos, she found that onerous and quickly turned to remembering then jotting notes on her phone in spare moments. The methods used to track personal information also changed depending on the topic and what we learned from the successes and failures of previous topics.

Reflection and Design
Though listed as its own step, this step was often intermingled with the surrounding steps of data collection and making. In this step, we reflected on the data and materials at hand to determine the design of our data narratives. It is this step where we decided what we were going to make, how it was going to be made, and what information would be embedded into the artefact. As with the previous step, there were no formal constraints. We chose what to make and how "readable" our data artefact should be. The final design was often determined by an accumulation of influences: the data collected, the personal experience, the materials, and a vision of the final artefact.
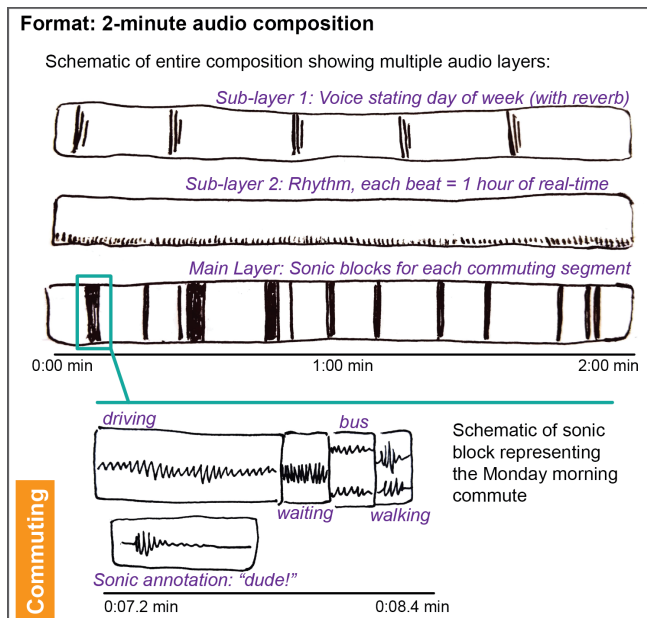
Embedding Narrative Intent
The next step is the execution of making the data narratives. Here we collected the materials we were going to use and considered how they might bring life into the intended narratives. While making the objects, we were not bound by our original design ideas; sometimes our data narratives were redesigned due to complications in material, time, or data.

Discovery of a Narrative
Our last step involved exchanging and interpreting the artefacts—independently and then together. First, Mikhaila received the sonification and Jordan received the physicalization, with no explicit guidance other than knowledge of the general data collection topic. With these unfamiliar artefacts in hand, we recorded our voices (roughly 5 to 10 minutes) as we reacted to them for the first time and tried to interpret *a* possible narrative. While interpreting a narrative, we sometimes relied on our knowledge of each other or what information we had collected ourselves. A few days later, we met in person to discuss (roughly 30 minutes) what we thought the unfamiliar

Format: 2-minute audio composition

Schematic of entire composition showing multiple audio layers:

Sub-layer 1: Voice stating day of week (with reverb)

Sub-layer 2: Rhythm, each beat = 1 hour of real-time

Main Layer: Sonic blocks for each commuting segment

0:00 min   1:00 min   2:00 min

driving   *bus*   Schematic of sonic block representing the Monday morning commute

waiting   *walking*

Sonic annotation: "dude!"

0:07.2 min   0:08.4 min

Commuting

Figure 2. Mikhaila's (non-maker) interpretation: The underlying tone appears at same interval throughout and could represent the monotony of commuting every day. It's linear, each day in sequence. A fast "doo" might represent missing the bus. A loud crackle is disruptive, possibly signifying frustration with bad drivers and traffic. There are short snippets of voices, which could be conversations, but based on knowledge of Jordan, are more likely podcasts. Jordan's (maker) interpretation: I originally wanted to find out how the length of sub-segments (i.e., amount of time waiting for bus) of my commute fluctuate day-to-day. Instead, hearing an entire week at once made me realize that although commutes feel long, they are short compared to the fabric of life, thus fluctuations of a few minutes here or there are not important.

artefact's narrative is and to explain what we had actually done. During this period, we also discussed what we learned by creating the object, what we would have done differently, and something we were thinking about for a future object (without revealing our full intent).

We analyzed our data—the artefacts, notes that we took while creating them, spoken reactions to the them, and discussions we had with each other about them—using a thematic analysis approach [8], where we identified key themes and iterated on them until we reached agreement.

THE ARTEFACTS

In this section, we present the work produced for each topic—commuting, forgetting, and busy-ness. Each artefact is represented by a figure and caption explaining the interpretations by both Mikhaila and Jordan. As the artefacts are either sound compositions, which cannot be printed on a page and must be experienced, or crafted objects, which have additional textures and forms not easily captured in a still image, we strongly encourage readers to experience the objects through our supplementary material as well. Below, we include brief, first-person narratives describing our basic processes of making and aesthetic and functional choices. Further details are included throughout the findings to illustrate specific themes. Full data collection and design journals are available in the supplementary materials.
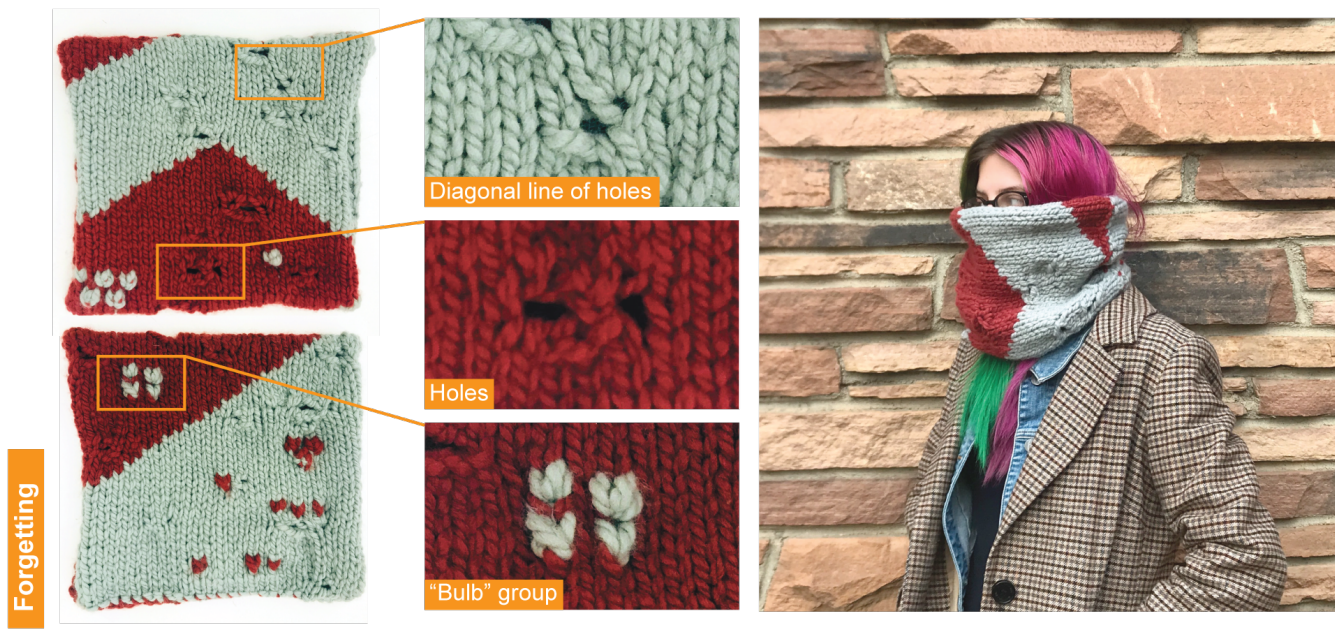
Making with Yarn

With all of my artefacts, I used tools (crochet hooks and knitting needles) and materials that I had on hand or that I found on sale at a craft store. I was motivated to use what I had on hand as I can be a bit of a craft-hoarder. In creating my artefacts, I found that I design for both function and aesthetic. For my commuting artefact (fig. 1), I wanted to represent segments of my commute (car or bus), the decisions behind them (convenience, price, time), and how I generally felt while commuting (frustrated, anxious, indifferent). Since I had been playing with crocheting different shapes the week prior, I wanted to create both squares and triangles. I originally wanted to create a larger patchwork (to possibly turn into a pillow), but I ran out of time and instead chose one day to transform into the artefact. With my second personal data narrative (fig. 3), I knew that I wanted to make a scarf before I had even finished collecting information on forgetting. I have knitted scarves many times before with bulky yarn, thus I knew I would have no problem finishing a scarf within a week's time. It then became a question of what to visualize, and I decided to focus on how disruptive remembering I forgot had been and the feeling of just forgetting. The form for the last artefact came as I was writing my daily journal entry on how busy my day had been. In trying to think of what I could make, I thought about what is a thing people do when they are really busy: drink lots of coffee. My last personal data narrative became a mug cozy (fig. 5), something to put on a coffee cup to keep your hands from burning; its function relates to when I am at my busiest and its look mirrored a calendar.

Making with Sound

I made all of the sound artefacts in sound editing software (Adobe Audition). For commuting, I was unsure of my abilities in sonification and thus focused on a straightforward mapping between duration data and the length of sound elements. The result is a short composition scaling down five complete days of data (fig. 2), using sounds from Freesound.org and a few of my own recordings to construct sonic blocks for each commuting segment. For forgetting, I challenged myself to create a sound artefact that didn't unfold temporally and could be explored non-linearly. This guided my data collection and analysis, which produced categorical clusters of types of forgettances. During data collection, I found and fell in love with a dataset [1] of humans imitating familiar sounds [9], like birds or home appliances. The strange-yet-familiar echo of multiple voices imitating the same sound resonated with my experiences of forgetting. Using these sounds, I created 30 short compositions (fig. 4), one for each forgettance, and presented them via a web interface[2]: the listener clicks a button to hear a random sound. For busy-ness, I collected daily journal entries describing the things I had to do each day along with a 1 to 10 score for the perceived and actual effort. I was struck by how wrong my perceptions were and imagined a voice assistant-controlled to-do list that could help me recalibrate my own perceptions. I presented this in the form of a short audio drama (fig. 6) that contains short vignettes of conversations between me and an Alexa device.

[1] https://github.com/interactiveaudiolab/VocalImitationSet
[2] https://jwirfs-brock.github.io/sounds-of-forgetting/forgetting.html

Figure 3. Jordan's (non-maker) interpretations: The diagonal line connecting a series of holes could represent forgetting the same thing over and over again. The two colors could denote different categories of forgetting (school/life). The scarf itself is circular, no beginning or end, which could point to how forgetting and remembering is circular. Mikhaila's (maker) interpretations: The number of "bulbs" in each group represents how disruptive remembering I forgot something was—least (1) to most (5) disruptive. Holes represent things that are completely forgotten (i.e. things not remembered).

FINDINGS

In this section, we present four major themes we identified through our paired autobiographical design and reflection process: negotiations between the data and the materials; accepting the will of the materials to co-author; contrasting the data of the experience and the experience of collecting data; and the multiplicity of data narratives through the role of interpreter as re-maker. We illustrate each theme with qualitative data drawn from the creation and interpretations the six artefacts, our reflective design process, and our discussions about them.

Matching Data to Materials (and Vice Versa)

In this section and the following, we introduce two themes about the effects of materials in designing our data narratives. By constraining ourselves to materials that we, individually, found interesting and familiar, we found ourselves negotiating between the data and materials. One negotiation we both questioned was in the choice of material constraint and degree to which we wanted to present "accurate" representations of the data. For example, while collecting data on forgetting Jordan discovered an online library containing people recreating every day sounds. Because she is a self-described sound nerd, she obsessed over the library and knew that she wanted to find a way to use it within her sonification (fig. 4). So when it came time to design her sonification, she loosely assigned sound effects to a related category—sometimes negotiating how *related* to the category the sound actually was. In this case, the chosen material took priority over the accuracy of the data represented. Mikhaila discovered this as well in their creation of the commuting patches (fig. 1). Structurally, they wanted to use a 2:1 triangle to square ratio for the commuting patches as that would allow them to create a coherent larger shape using the two smaller shapes. To do so, they had to create groupings of the data that fit within those bounds and ratios. They first attempted to group commute segments by bus versus car, but that resulted in a 3:1 ratio. That led them to the final grouping of typical (their car and normal bus route) and atypical (everything else) modes of transportation that could accommodate the desired ratio.

Complementing the negotiation above, the data collected also created inherent design constraints for the material. In the commuting sonification (fig. 2), Jordan had collected her commuting data before choosing the sounds for her data narrative. Thus, while designing her commuting sonification, she chose sounds related to that commute segment (car ride -> engine sound) and event (someone pulled over -> siren). Different from before, where the data was being fit to the materials, here the data is determining what material should be used: each entry of data was telling Jordan with whom (what sound) it could work and co-exist. Thus, Jordan navigated the negotiations and preserved the data integrity through related sounds.

Another type of negotiation was that of representing the data more accurately while keeping the spirit of the material. In making the forgetting scarf (fig. 3), Mikhaila always reiterated that they wanted it to "*feel* like forgetting and remembering you forgot." They decided to create "bulb" groups, representing the things they remember that they forgot and disrupting the flow of the knitted scarf, and holes, representing the truly forgotten items like holes in their memory. This example shows how the materials allowed for the representation of the data and the data allowed for the nature (here, tactile) of the material to be prominently featured in the artefact. Each of the examples and types of negotiations above show the reciprocal

relationship between materials and data and how we as makers mediated those negotiations to design our data narratives.

Accepting the Materials' Will to Co-Author

Using materials that are not common in mainstream data representations—yarn and sound—allowed us to approach the act of creating as sense-making in new ways. Our materials had an agency of their own; they did unexpected things that shaped our artefacts and our narratives. Drawing on Bennett's ideas of *thing power*, we were particularly attuned to "those occasions in ordinary life when the us and the it slipslide into each other, for one moral of this materialist tale is that we are also nonhuman and that things too are vital players in the world." [4] For example, while crocheting the busy-ness mug cozy (fig. 5), Mikhaila realized that the yarns on the back side were becoming increasingly entangled with each other as they worked from row to row. They took this as the materials telling them that in addition to the columned, calendar-like display of busy-ness, the reverse side could be a jumbled mess showing how being busy can feel: like trying to juggle five

Figure 4. Mikhaila's (non-maker) interpretation: After clicking "YES" button several times, some noises sound like maybe they are the same, there might be a connection between the sounds being played and what was forgotten. I tried to not forget sounds I was hearing in an attempt to decode them; however, this was frustrating as I both forget what I had heard, and was confounded by sounds that were similar but not exactly the same. I could recognize a cuckoo clock and a "zing," but they sounded different every time. Tried to ignore all other sounds and focus on figuring out what the "zing" meant, perhaps items remembered then forgotten again. Eventually accepted the frustrating nature of the piece, which wanted me to forget what I had heard and not quite be able to decode the meaning. Jordan's (maker) interpretation: Through clustering (analysis) and working with groups of sounds, I became obsessed with types of forgetting, and completely ignored any attempt to search for temporal patterns (what do I forget on Mondays, or in afternoons?).

yarns as an amateur crafter. Therefore, instead of cutting the yarns and hiding them within the crochet stitches, Mikhaila listened to the materials and kept the reverse messy, adding a hidden layer to the mug cozy. Similarly, while creating the sound composition for busy-ness (fig. 6), Jordan found that using a voice assistant—Amazon's Alexa—to repeat non-words required her to relinquish sonic control to the text-to-speech function. Just as we as humans had ideas for what the material should be doing, we sensed the materials also had procedures they wanted to follow.
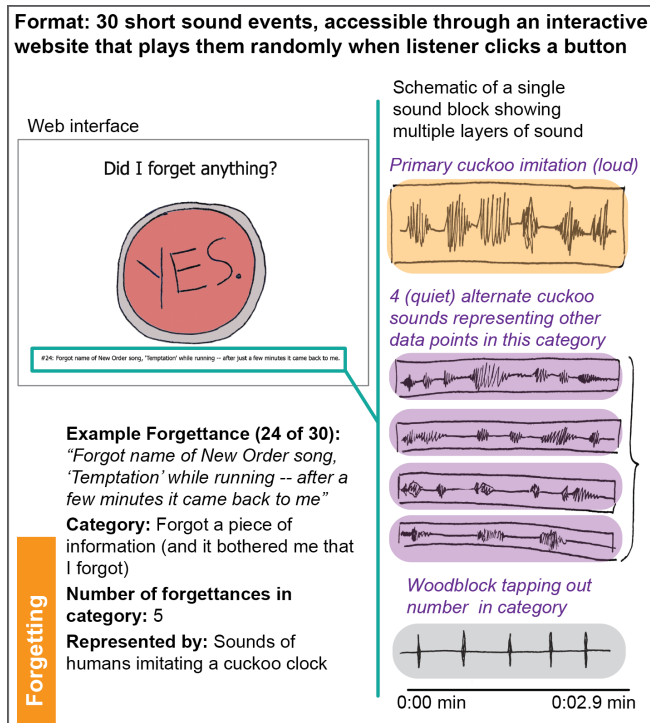
The examples above show the material explicitly voicing an opinion during the making process, but sometimes the will of the material was hidden until the object was completed—activated in interpretation rather than creation. In designing the forgetting scarf, Mikhaila pseudo-randomly (i.e. with an aesthetic in mind) chose locations for the holes. At one end of the scarf, they placed a diagonal series of holes, and because of how stitches were increased and decreased, there became a diagonal line that visually connects the holes. However, Mikhaila had not noticed this diagonal until Jordan pointed it out while discussing her interpretation. The combination of the bulky yarn and the knitting process acted as a silent author of an additional story to the personal data narrative.

In addition to our chosen materials (yarn and sound), time also proved itself to be a material co-author. We attempted to keep the making of our artefacts to a week's time. Viewing time as a type of material, it brings to light how we rearranged our design and narratives to fit within the time frame. The original commuting patchwork was supposed to be 24 patches (16 triangles and 8 squares) stitched together to create the front-side of a pillow. However, it became clear to Mikhaila that a week would not be enough time, so they chose to visualize one particularly interesting day through 6 patches. Jordan also worked with time during the commuting artefact. She originally wanted to use entirely original recordings, but because of the time it would take to collect and edit those sounds, chose to grab most sounds from Freesound.org. We learned from this process of listening to "time" on what could be narrative, which then became a part of the design process of the future artefacts on forgetting and busy-ness.

While this theme is related to the previous one, we see a difference in our role as the human. Before, we were acting as a mediator while the materials and data compromised on design. Alternatively, we also realized the narrative being determined by *other* materials outside of our control (e.g. time, interpreters) and learned not just to accept that, but to embrace the new perspectives it brought forth. Arguably all materials—including the digital tools often used for visualization—have agency and will, but by working with familiar materials in an unfamiliar way, employing them to create data narratives, we became attentive to their material agency and the interpretations they were introducing.

Data of the Experience versus Experience of the Data

In embracing the subjectivity and inaccuracy of our data collection, we became attuned to the ways that the data we were collecting *about* our lived experience departed from our perceptions of those lived experiences. In some cases, data collection

Figure 5. Jordan's (non-maker) interpretations: There are five distinct columns, so each column could represent a day of the week. The leftmost being Monday and the rightmost being Friday. Each row could represent an hour and the color represents how busy they were because there is a natural spectrum of tan to maroon. The moments when there are super-imposed rows could be when the perceived busy-ness did not match actual busy-ness. Mikhaila's (maker) interpretations: Each column represents a day, but I accidentally flipped so leftmost is Friday and rightmost is Monday. Each color represents a category of an event: meeting/appointment (red), class (orange), work (yellow), and self-made freetime (green). Tan is time of no particular importance. Additionally, the red/yellow and yellow/red lines containing the center rows are sunrise (bottom) and sunset (top). Rows on top of each other are events scheduled in the same hour. The inside ended up being a tangled mess of yarns and came to represent how hectic busy-ness feels.

served as a counter-argument that overturned the perception of lived experience, as happened in Jordan's experience of collecting busy-ness data. By consciously documenting perceived and actual stress produced by her obligations—and by forcing herself to impute these feelings into numeric scores—she realized just how wrong her perceptions actually were. Items that she had been procrastinating and dreading were easy and painless; items that she thought would be straightforward ended up being stressful and time-consuming. One individual task even fluctuated between minimum and maximum levels of both perceived *and* actual busy-ness. The discrepancies between perceived and actual busy-ness—both, still, perceived through the experience of data collection—inspired Jordan to continue looking for patterns in her perceptions and actions.

While in the above example, the experience of collecting data made the lived experience more accessible, our experiences of collecting data about forgetting highlighted how inaccessible and resistant to data collection some experiences are. We both acknowledged and grappled with the paradoxical nature of collecting data about forgetting, which can only be done through remembering, and dealt with this discrepancy in different ways. Mikhaila did this by representing data about un-noted forgettances—moments that they knew must exist, yet could not prove—as holes in the scarf (fig. 3). By representing data that refused collection through the absence, rather than presence, of yarn, she evoked lost data without explicitly fabricating it. Jordan dealt with the un-collectable data in a different way, through creating a confounding, familiar-yet-strange interface for her sonic artefact (fig. 4) that recreated the feeling of forgetting.

Combining the act of *collecting* data with the act of *making* with data highlighted additional discrepancies between the lived experience and the experience of data. In creating the commuting artefacts (fig. 1 & 2), the negotiations between data and materials, described above, caused us to shift our gazes, highlighting elements of the lived experience that we

did not necessarily plan to collect data about. Mikhaila had originally intended to create crocheted objects for each day of the week, and then due to time and materials limitations only created objects for one day. Instead of narrowing the scope, this shifted the focus, allowing us to hone in on the intricacies of a single day. Alternatively, Jordan had originally collected timestamps for way points along her commute (what time she reached an intersection, what time she reached the bus stop), and had intended to make a "zoomed in" view contrasting the length of the sub-segments of her commute day to day. Instead, after first creating a "zoomed out" view of an entire week of commuting, she realized how little of her total time is spent commuting—even though it may cause a disproportionate amount of stress. Those fluctuations in commute sub-segment times now seemed insignificant. These shifts in perspective, which allowed the authors to access different elements of the lived experience than they originally intended, happened through the processes of collecting data and making with it.

Co-Existence of Multiple Narratives
Through the course of this project, multiple data narratives emerged and influenced each other around each artefact—the narratives of data collection and reflection, of the maker while creating, of the interpreter exploring the foreign artefact alone, and of mutual discussion as the two maker/interpreters came back together to understand their creations through the eyes of the other author. We invited this multiplicity by exchanging the objects without any key or guide while also actively attempting to make our narratives legible to the other. This encouraged us to not think of the artefacts as having one true meaning to be transmitted and discovered. Instead, we saw the narratives embedded as clues that could be read in multiple ways, all of which could generate valid reflective insights. Multiple narratives emerged through interpretation and revealed themselves through mutual discussion.

We observed this narrative multiplicity in moments where the interpreter found meaning that differed from the maker's
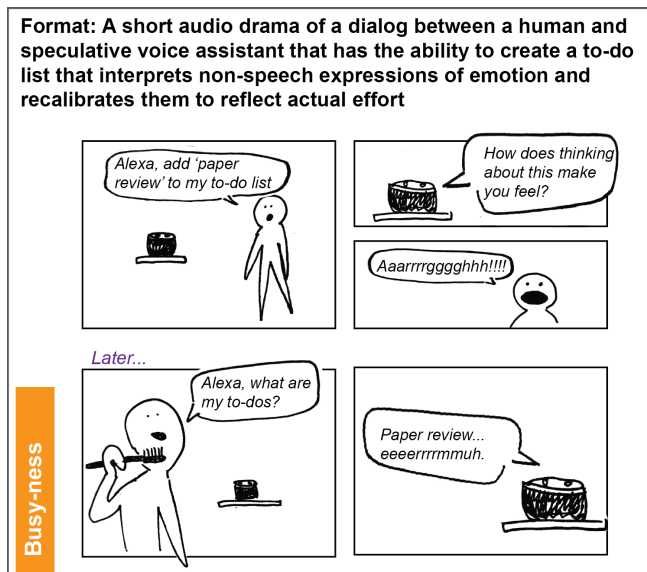
Figure 6. Mikhaila's (non-maker) interpretation: Alexa moments are sprinkled through daily life actions (training dog, brushing teeth), showing how she thinks about obligations while doing the mundane (i.e. in-the-moment to-do list creation). She builds the to-do list by making a voice memo about how much she is dreading it, but when Alexa repeats it, the vocalization becomes a mess of sounds and non-words. Alexa's mispronouncing and playful tone of vocalizations feels like a commentary on how we dread things we have to do, but they are not as bad as we think. Although this is audio, I can almost see the story happening as if it were a commercial or a skit. Jordan's (maker) interpretation: I realized how wrong my perception actually was. There was not necessarily a standard pattern—that is, I couldn't create an algorithm for systematically converting my perception into reality. But with more data collection and contextual information, could I? Listening back to my artefact, I realized that I might not use it as I intended, but might instead turn it into a game, trying to manipulate and guess Alexa's responses.

explicit intentions: When Mikhaila listened to Jordan's commuting composition, Mikhaila perceived the rhythmic underbeat—which Jordan intended solely as a metronome offering a clue about the timescale—as conveying the monotony of daily commuting. Another example is that Jordan included the sounds of brushing teeth (fig. 6) and training a dog solely as scene-setting devices to emphasize that this was a story happening in the context of someone's real life, whereas when Mikhaila listened, they interpreted these sounds as everyday to-dos that contrast with the more stressful work-related to-dos that were expressed through the interactions with a voice assistant device. Thus the interpreter found meaning that did in fact echo the maker's experience, although it was not consciously embedded in the narrative.

In other moments, the maker and interpreters developed distinct languages for describing the details of the artefacts—in turn, these languages raise new questions about the nature of the data and the experience. Jordan, while interpreting Mikhaila's yarn artefacts, developed a taxonomy of discontinuities in the knits: "mountains" with "caves," "holes," and "warts." Yet what Jordan called warts, Mikhaila, the maker, called "bulbs." Calling something a wart or a bulb might change the way we think about the experience it represents, moments of forgetting. A wart has negative connotations: it is

a blemish. Whereas a bulb is something one plants, that can grow if nourished. These contrasting languages for the same object-data make us question whether forgetting is destructive or generative, or perhaps both.

We also observed experiential narratives that took place through the acts of reading/interpreting: Mikhaila felt disoriented, frustrated, yet intrigued by the echoing sonic themes of the atemporal forgettances sound composition (fig. 4) and embarked on a puzzle-solving process that is its own narrative, existing only in that moment in time; Jordan felt calmed and soothed by the more "breathable" days on the busy-ness mug cozy (fig. 5), and anxious about the densely packed days. While interpreting the mug-cozy, Jordan was also intrigued by the functionality of the object—it keeps your hands from burning while holding a hot drink—and thus imagined using this in the future, while looking at the embedded data and reflecting on current and past busy-ness. This points to how some of the multiple narratives that emerged through interpretation layer imagined or remembered experience onto the artefacts. Mikhaila, while listening to the commuting sonification (fig. 2), used their knowledge of Jordan's interests to conclude that the snippets of dialog were probably radio or podcast clips and not inter-personal conversations. And Jordan, while interpreting the forgetting scarf (fig. 3), was keenly aware of how her lack of knowledge about knitting, combined with not knowing exactly what data Mikhaila collected, forced her to heavily rely on her experiences with forgetting as an interpretive lens.

DISCUSSION

Our experiment helped us connect several strands of research taking place in studies of materiality and interpretation for the purposes of extending conversations on personal informatics. Like Devendorf [16], Dew [17] and Liu [47], we opened ourselves and practices up to the possibility of sensing our materials in new ways and, in turn, our materials revealed to us both new forms as well as interpretations. Additionally, we began to sense the material and lively behaviors of things we may not have previously considered material, like time and language. Data became one material among others [70], no more or less important in design. In the spirit of reflective design [62], we found ourselves embracing the possibility of holding multiple, even conflicting, narratives as true [63]. Where we feel our work provides most clarity, and potential to shape futures of personal informatics, is in the way the work entangles the roles of maker and interpreter.

In the following section we explore the roles of maker and interpreter and offer new insights into these roles to the community. We end our discussion by expanding on how our work has implications to research in personal informatics and what future work might look like.

Entangling the Roles of Maker and Interpreter

Through our research process, we discovered that while we had intentionally designed narratives encoded into our objects, they diverged from the interpreted narratives in unexpected ways. This generative dissonance led to new understandings of personal data artefacts, disentangling a multiplicity of narratives from the materials. We now return to our original ques-

tions about personal data narratives—*Where do the boundaries between maker and interpreter emerge with data things?* and *Who or what has the authority to interpret narrative and assign meaning to data things?*—with this perspective. We entangle the roles of maker and interpreter by foregrounding the validity of both of our interpretations of each artefact. Rather than seeing these narratives as distinct, we see them as productively informing each other. For instance, one interpretation provides new metaphors and modes of understanding the experiences and rewriting the meaning of each artefact. In doing so, we question the authority we *thought* we had as makers.

Our turn away from the authority of the maker, or data "author," reminded us of Barthes' literary critique, "The Death of the Author" [3]. Addressing how we should interpret written texts, Barthes argues that the intentions and biographical context of the author should hold no power in our ability to distill meaning from a text. He writes, "a text is multiple writings" from various cultural sources, and the "one place where this multiplicity is focused" is with the reader, not the author. Readers have the power to dynamically engage multiple meanings and interpretations—something an author, who has a static relationship to a text once it is published, cannot do. To Barthes, for the reader to be born, the author must die.

Translating Barthes' ideas to personal informatics and data narratives, we substitute 'maker' and 'interpreter' for 'author' and 'reader', respectively. We make this switch in language to emphasize the processes through which we conducted our research, but the terms may be read interchangeably. Addressing the question of the boundaries between maker and interpreter, our work suggests that rather than dying, the maker is reborn as interpreter and the interpreter is reborn as maker. Throughout this process, we found ourselves constantly vacillating between maker and interpreter. As makers, we would pause to interpret and change the course of our design actions; as interpreters, we would re-make the artefacts in our minds and in our discussions about them. By allowing ourselves to inhabit both roles, continually being reborn from one to the other, we shift the authority to an individual within the context of the self. By viewing the process as a rebirth, we find that the multiple narratives co-exist and no narrative is more 'right.' Thus, addressing the question of authority, no one has authority over another person in determining the narrative of an artefact and no narrative invalidates another.

Within this reinterpretation of the roles of maker and interpreter, materials form a unique role. Barthes' argued that it is actually *language*, not the author, that speaks through written texts; likewise, the *material*—data, sound, yarn, time, etc.—not the maker, speaks through the artefact. We view materials as makers of artefacts in their own right. As such, the materials themselves have the ability to embed intentional narratives within the artefacts, holding the multiple narratives to be interpreted by others. Thus the conventional model of a maker, working with a material, passing along an artefact to an interpreter who decodes a narrative, can be reinterpreted as: an entanglement of humans and materials as makers and interpreters, working both collectively and independently to articulate multiple, co-existing narratives. We emphasize, like

Barthes, that we are not *deciphering* an ultimate meaning or truth of the artefacts, rather we are *disentangling* a multiplicity of narratives from the materials.

Implications and Future Work

Considering a new role of maker-interpreter, we suggest areas of future work for DIS and personal informatics communities: Recognizing the agency of materials, we are intrigued by the potential for materiality to allow us to selectively conceal and reveal certain aspects of data narratives. Might bespoke data representations, in materials that are easy to share yet require special knowledge to create, allow makers and interpreters to have more control over who has access to our personal data and the associated narratives? Our research process was mediated by the fact that we have a personal and professional relationship that allowed us to share sensitive information and grant each other access to our creative processes. If strangers, rather than friends, exchanged data things, perhaps the process of being constantly reborn from maker to interpreter and back again might be quite different. By pairing unknown people to exchange data things, future work could explore the roles of familiarity and strangeness in collaborative maker and interpreter relationships.

Through our research, we found meaning in each other's data artefacts. Some of that meaning was unintended, something the maker had not consciously embedded, yet ultimately embraced. Other times, that meaning seemed arbitrary—the interpreter straining to find meaning where perhaps there was none. This evokes the concept of *apophenia* [48], which is the human tendency to associate connections between unrelated events. This observation makes us wonder if simply stating that data has been somehow involved in the creation of an artefact causes it to be read in a particular light. Seen another way, it highlights the slippery nature of describing (or quantifying) human experiences by substituting partiality with prompts for imaginative reconsideration of experiences.

Our work also suggests new ways of self-tracking that decentralize data and the individual and foreground the processes of collaborative making and interpreting (in a similar fashion to [33] and projects like *Dear Data*). Pierce's notion of counter-functionality could be useful for actively limiting one's access to the original or source material or narrative [56]. For instance, we can imagine apps that give you assignments for creating with your data (i.e. performing sleep data as a song); or that allow you to design an artefact from your data, then once the object is made, the data ceremoniously disappears forever; or, a 'chat roulette' for narrative data artefacts, encouraging interpretation with strangers.

CONCLUSION

In this paper we have presented a paired, autobiographical exchange of personal data narratives in yarn and sound. Our work suggests that an artefact can have multiple narratives that co-exist and that the authority of narrative is distributed between materials and humans. We elaborate on our roles of maker and interpreter, where the boundaries are circular and we are constantly being reborn from one to the other. We contribute our maker-interpreter concept to the DIS community and offer paths for future work.

REFERENCES

[1] Jason Alexander, Yvonne Jansen, Kasper Hornbæk, Johan Kildal, and Abhijit Karnik. 2015. Exploring the Challenges of Making Data Physical. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing System (CHI EA '15)*. ACM, New York, NY, USA, 2417–2420. DOI: http://dx.doi.org/10.1145/2702613.2702659

[2] Amid Ayobi, Tobias Sonne, Paul Marshall, and Anna L. Cox. 2018. Flexible and Mindful Self-Tracking: Design Implications from Paper Bullet Journals. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, 1–14. DOI: http://dx.doi.org/10.1145/3173574.3173602

[3] Roland Barthes. 2006. The Death of the Author. In *Participation*. Whitechapel and The MIT Press, London, UK, 41–45. (Original work published in 1968).

[4] Jane Bennett. 2004. The force of things: Steps toward an ecology of matter. *Political theory* 32, 3 (2004), 347–372.

[5] Rae Ellen Bichell. 2016. Social Security Data Errors Can Turn People Into The Living Dead. (10 August 2016). https://www.npr.org/sections/health-shots/2016/08/10/489318279/social-security-data-errors-can-turn-people-into-the-living-dead.

[6] Leslie Birch. 2016. This Innovative Tech Dress Brings Colorful Diary to Life #WearableWednesday #WearableTech @ITP_NYU. (2016). https://blog.adafruit.com/2016/12/14/this-innovative-tech-dress-brings-colorful-diary-to-life-wearablewednesday-wearabletech-itp_nyu/.

[7] Chris Bopp, Ellie Harmon, and Amy Voida. 2017. Disempowered by Data: Nonprofits, Social Enterprises, and the Consequences of Data-Driven Work. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 3608–3619. DOI: http://dx.doi.org/10.1145/3025453.3025694

[8] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

[9] Mark Cartwright and Bryan Pardo. 2015. Vocalsketch: Vocally imitating audio concepts. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, New York, NY, USA, 43–46. DOI:http://dx.doi.org/10.1145/2702123.2702387

[10] Alan Chamberlain, Mads Bødker, and Konstantinos Papangelis. 2017. Mapping Media and Meaning: Autoethnography as an Approach to Designing Personal Heritage Soundscapes. In *Proceedings of the 12th International Audio Mostly Conference on Augmented and Participatory Sound and Music Experiences* (2017-08-23) *(AM '17)*. ACM, New York, NY, USA, 1–4. DOI:http://dx.doi.org/10.1145/3123514.3123536

[11] Keke Chen and Ling Liu. 2004. ClusterMap: Labeling Clusters in Large Datasets via Visualization. In *Proceedings of the Thirteenth ACM International Conference on Information and Knowledge Management (CIKM '04)*. ACM, New York, NY, USA, 285–293. DOI: http://dx.doi.org/10.1145/1031171.1031233

[12] Stuart Cornejo and Duncan Haffenden. 2018. Towards ecological and embodied design of auditory display. In *Proceedings of the 24th International Conference on Auditory Display (ICAD '18)*. Georgia Institute of Technology, Atlanta, GA, USA, 191–196. DOI: http://dx.doi.org/10.21785/icad2018.016

[13] Kate Crawford, Jessa Lingel, and Tero Karppi. 2015. Our metrics, ourselves: A hundred years of self-tracking from the weight scale to the wrist wearable device. *European Journal of Cultural Studies* 18, 4 (2015), 479–496. DOI: http://dx.doi.org/10.1177/1367549415584857

[14] Audrey Desjardins and Timea Tihanyi. 2019. Listening Cups: A Case of Data Tactility and Data Stories. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. ACM, New York, NY, USA, 147–160. DOI: http://dx.doi.org/10.1145/3322276.3323694

[15] Laura Devendorf, Kristina Andersen, Daniela K. Rosner, Ron Wakkary, and James Pierce. 2019. From HCI to HCI-Amusement: Strategies for Engaging What New Technology Makes Old. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, 35:1–35:12. DOI:http://dx.doi.org/10.1145/3290605.3300265

[16] Laura Devendorf, Abigail De Kosnik, Kate Mattingly, and Kimiko Ryokai. 2016. Probing the Potential of Post-Anthropocentric 3D Printing. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16)*. ACM, New York, NY, USA, 170–181. DOI: http://dx.doi.org/10.1145/2901790.2901879

[17] Kristin N. Dew and Daniela K. Rosner. 2018. Lessons from the Woodshop: Cultivating Design with Living Materials. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article Paper 585, 12 pages. DOI:http://dx.doi.org/10.1145/3173574.3174159

[18] Chris Elsden, Abigail C. Durrant, David Chatting, and David S. Kirk. 2017. Designing Documentary Informatics. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)*. ACM, New York, NY, USA, 649–661. DOI: http://dx.doi.org/10.1145/3064663.3064714

[19] Chris Elsden, Bettina Nissen, Andrew Garbett, David Chatting, David Kirk, and John Vines. 2016. Metadating: Exploring the Romance and Future of Personal Data. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 685–698. DOI: http://dx.doi.org/10.1145/2858036.2858173

[20] Daniel A Epstein, An Ping, James Fogarty, and Sean A Munson. 2015. A lived informatics model of personal informatics. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)*. ACM, New York, NY, USA, 731–742. DOI: http://dx.doi.org/10.1145/2750858.2804250

[21] Sarah Fox, Noura Howell, Richmond Wong, and Franchesca Spektor. 2019. Vivewell: Speculating Near-Future Menstrual Tracking through Current Data Practices. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. ACM, New York, NY, USA, 541–552. DOI: http://dx.doi.org/10.1145/3322276.3323695

[22] Michael Friendly. 2008. A Brief History of Data Visualization. In *Handbook of Data Visualization*. Springer Berlin Heidelberg, Berlin, Heidelberg, 15–56. DOI:http://dx.doi.org/10.1007/978-3-540-33037-0_2

[23] Bill Gaver, Tony Dunne, and Elena Pacenti. 1999. Design: cultural probes. *interactions* 6, 1 (1999), 21–29.

[24] Jacob Goldstein and David Kestenbaum. 2011. U.S. Home Prices, Sung As Opera. (26 April 2011). https://www.npr.org/sections/money/2011/04/27/135737940/the-case-shiller-index-sung-as-opera

[25] Visda Goudarzi. 2016. Exploration of sonification design process through an interdisciplinary workshop. In *Proceedings of the Audio Mostly 2016*. ACM, New York, NY, USA, 147–153. DOI: http://dx.doi.org/10.1145/2986416.2986422

[26] Rebecca Gulotta, Alex Sciuto, Aisling Kelliher, and Jodi Forlizzi. 2015. Curatorial agents: How systems shape our understanding of personal and familial digital information. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 3453–3462. DOI:http://dx.doi.org/10.1145/2702123.2702297

[27] Kevin D Haggerty and Richard V Ericson. 2000. The surveillant assemblage. *The British journal of sociology* 51, 4 (2000), 605–622.

[28] Otto Hans-Martin Lutz, Jacob Leon Kroger, Manuel Schneiderbauer, and Manfred Hauswirth. 2019. Surfing in sound: Sonification of hidden web tracking. In *Proceedings of the 25th International Conference on Auditory Display (ICAD 2019)*. Georgia Institute of Technology, 306–309. DOI: http://dx.doi.org/10.21785/icad2019.071

[29] Daniel Harrison, Paul Marshall, Nadia Bianchi-Berthouze, and Jon Bird. 2015. Activity Tracking: Barriers, Workarounds and Customisation. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)*. ACM, New York, NY, USA, 617–621. DOI:http://dx.doi.org/10.1145/2750858.2805832

[30] Karey Helms. 2019. Do You Have to Pee? A Design Space for Intimate and Somatic Data. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. ACM, New York, NY, USA, 1209–1222. DOI: http://dx.doi.org/10.1145/3322276.3322290

[31] Noura Howell, Laura Devendorf, Rundong (Kevin) Tian, Tomás Vega Galvez, Nan-Wei Gong, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. Biosignals As Social Cues: Ambiguity and Emotional Interpretation in Social Displays of Skin Conductance. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16)*. ACM, New York, NY, USA, 865–870. DOI: http://dx.doi.org/10.1145/2901790.2901850

[32] Noura Howell, Laura Devendorf, Tomás Alfonso Vega Gálvez, Rundong Tian, and Kimiko Ryokai. 2018. Tensions of Data-Driven Reflection: A Case Study of Real-Time Emotional Biosensing. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, 431:1–431:13. DOI: http://dx.doi.org/10.1145/3173574.3174005

[33] Noura Howell, Greg Niemeyer, and Kimiko Ryokai. 2019. Life-Affirming Biosensing in Public: Sounding Heartbeats on a Red Bench. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, 680:1–680:16. DOI: http://dx.doi.org/10.1145/3290605.3300910

[34] Carmen Hull and Wesley Willett. 2017. Building with Data: Architectural Models as Inspiration for Data Physicalization. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 1217–1264. DOI:http://dx.doi.org/10.1145/3025453.3025850

[35] Samuel Huron, Pauline Gourlet, Uta Hinrichs, Trevor Hogan, and Yvonne Jansen. 2017. Let's Get Physical: Promoting Data Physicalization in Workshop Formats. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)*. ACM, New York, NY, USA, 1409–1422. DOI: http://dx.doi.org/10.1145/3064663.3064798

[36] Jonna Häkkilä and Lasse Virtanen. 2016. Aesthetic physical items for visualizing personal sleep data. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct (MobileHCI '16)*. ACM, New York, NY, USA, 1173–1177. DOI: http://dx.doi.org/10.1145/2957265.2965019

[37] Dhruv Jain, Audrey Desjardins, Leah Findlater, and Jon E. Froehlich. 2019. Autoethnography of a Hard of Hearing Traveler. In *The 21st International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS '19)*. ACM, New York, NY, USA, 236–248. DOI:http://dx.doi.org/10.1145/3308561.3353800

[38] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and challenges for data physicalization. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 3227–3236. DOI: `http://dx.doi.org/10.1145/2702123.2702180`

[39] Annie Kelly, Matt Whitlock, Brielle Nickoloff, Angel Lam, Danielle Albers Szafir, and Stephen Voida. 2017. Becoming Butterflies: Interactive Embodiment of the Butterfly Lifecycle. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers (UbiComp '17)*. ACM, New York, NY, USA, 93–96. DOI:`http://dx.doi.org/10.1145/3123024.3123136`

[40] Da-jung Kim, Yeoreum Lee, Saeyoung Rho, and Youn-kyung Lim. 2016. Design Opportunities in Three Stages of Relationship Development between Users and Self-Tracking Devices. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 699–703. DOI: `http://dx.doi.org/10.1145/2858036.2858148`

[41] Nam Wook Kim, Hyejin Im, Nathalie Henry Riche, Alicia Wang, Krzysztof Gajos, and Hanspeter Pfister. 2019. DataSelfie: Empowering People to Design Personalized Visuals to Represent Their Data. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, 79:1–79:12.

[42] Hyosun Kwon, Joel E. Fischer, Martin Flintham, and James Colley. 2018. The Connected Shower: Studying Intimate Data in Everyday Life. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 4 (Dec. 2018). DOI:`http://dx.doi.org/10.1145/3287054`

[43] Steven Landry and Myounghoon Jeon. 2017. Participatory design research methodologies: A case study in dancer sonification. In *Proceedings of the 23rd International Conference on Auditory Display (ICAD '17)*. Georgia Institute of Technology, 182–187.

[44] Grace Li and Bruce N Walker. 2019. Mixed speech and non-speech auditory displays: impacts of design, learning, and individual differences in musical engagement. In *Proceedings of the 25th International Conference on Auditory Display (ICAD 2019)*. Georgia Institute of Technology, 133–139. DOI: `http://dx.doi.org/10.21785/icad2019.019`

[45] Ian Li, Anind Dey, and Jodi Forlizzi. 2010. A Stage-Based Model of Personal Informatics Systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 557–566. DOI: `http://dx.doi.org/10.1145/1753326.1753409`

[46] Ian Li, Anind K. Dey, and Jodi Forlizzi. 2011. Understanding My Data, Myself: Supporting Self-Reflection with Ubicomp Technologies. In *Proceedings of the 13th International Conference on Ubiquitous Computing (UbiComp '11)*. ACM, New York, NY, USA, 405–414. DOI: `http://dx.doi.org/10.1145/2030112.2030166`

[47] Szu-Yu (Cyn) Liu, Jeffrey Bardzell, and Shaowen Bardzell. 2019. Decomposition as Design: Co-Creating (with) Natureculture. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19)*. ACM, New York, NY, USA, 605–614. DOI: `http://dx.doi.org/10.1145/3294109.3295653`

[48] Dan Lockton, Some Paving, and Water Carriage. 2018. Apophenia As Method—Or, Everything Is Either A Metaphor Or An Analogue Computer.

[49] Giorgia Lupi and Stefanie Posavec. 2016. *Dear data*. Chronicle Books.

[50] Deborah Lupton. 2014. Self-tracking cultures: towards a sociology of personal informatics. In *Proceedings of the 26th Australian Computer-human interaction conference on designing futures: The future of design*. ACM, 77–86.

[51] Murali Mani and Si Fei. 2017. Effective Big Data Visualization. In *Proceedings of the 21st International Database Engineering & Applications Symposium (IDEAS 2017)*. ACM, New York, NY, USA, 298–303. DOI:`http://dx.doi.org/10.1145/3105831.3105857`

[52] David McGookin and Stephen Brewster. 2011. Earcons. In *The sonification handbook*. `https://sonification.de/handbook/chapters/chapter14/`

[53] Michael A Nees. 2018. Auditory graphs are not the "killer app" of sonification, but they work. *Ergonomics in Design* 26, 4 (2018), 25–28.

[54] John G Neuhoff. 2019. Is sonification doomed to fail?. In *Proceedings of the 25th International Conference on Auditory Display (ICAD '19)*. Georgia Institute of Technology.

[55] Bettina Nissen and John Bowers. 2015. Data-Things: Digital Fabrication Situated within Participatory Data Translation Activities. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2467–2476. DOI: `http://dx.doi.org/10.1145/2702123.2702245`

[56] James Pierce and Eric Paulos. 2014. Counterfunctional things: exploring possibilities in designing digital limitations. In *Proceedings of the 2014 conference on Designing interactive systems (DIS '14)*. ACM, New York, NY, USA, 375–384.

[57] Zachary Pousman, John Stasko, and Michael Mateas. 2007. Casual information visualization: Depictions of data in everyday life. *IEEE transactions on visualization and computer graphics* 13, 6 (2007), 1145–1152.

[58] Stephen Roddy and Brian Bridges. 2016. Sounding human with data: the role of embodied conceptual metaphors and aesthetics in representing and exploring data sets. In *Music Technology Workshop (MusTWork16)*.

[59] John Rooksby, Mattias Rost, Alistair Morrison, and Matthew Chalmers. 2014. Personal tracking as lived informatics. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 1163–1172.

[60] Kimiko Ryokai, Elena Durán López, Noura Howell, Jon Gillick, and David Bamman. 2018. Capturing, Representing, and Interacting with Laughter. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA. DOI: `http://dx.doi.org/10.1145/3173574.3173932`

[61] Alper Sarikaya and Michael Gleicher. 2017. Scatterplots: Tasks, data, and designs. *IEEE transactions on visualization and computer graphics* 24, 1 (2017), 402–412.

[62] Phoebe Sengers, Kirsten Boehner, Shay David, and Joseph 'Jofish' Kaye. 2005. Reflective Design. In *Proceedings of the 4th Decennial Conference on Critical Computing: Between Sense and Sensibility (CC '05)*. ACM, New York, NY, USA, 49–58. DOI: `http://dx.doi.org/10.1145/1094562.1094569`

[63] Phoebe Sengers and Bill Gaver. 2006. Staying Open to Interpretation: Engaging Multiple Meanings in Design and Evaluation. In *Proceedings of the 6th Conference on Designing Interactive Systems (DIS '06)*. ACM, New York, NY, USA, 99–108. DOI: `http://dx.doi.org/10.1145/1142405.1142422`

[64] Thomas Smith, Simon J. Bowen, Bettina Nissen, Jonathan Hook, Arno Verhoeven, John Bowers, Peter Wright, and Patrick Olivier. 2015. Exploring Gesture Sonification to Support Reflective Craft Practice. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 67–76. DOI: `http://dx.doi.org/10.1145/2702123.2702497`

[65] Simon Stusak and Ayfer Aslan. 2014. Beyond physical bar charts: an exploration of designing physical visualizations. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems (CHI EA '14)*. ACM, 1381–1386. DOI: `http://dx.doi.org/10.1145/2559206.2581311`

[66] Alexandra Supper. 2012. The search for the "killer application": Drawing the boundaries around the sonification of scientific data. In *The Oxford handbook of sound studies*. Oxford University Press, New York.

[67] Saiganesh Swaminathan, Conglei Shi, Yvonne Jansen, Pierre Dragicevic, Lora A. Oehlberg, and Jean-Daniel Fekete. 2014. Supporting the design and fabrication of physical visualizations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, 3845–3854. DOI: `http://dx.doi.org/10.1145/2556288.2557310`

[68] Tatiana Tekušová, Jörn Kohlhammer, Slawomir J. Skwarek, and Galina V. Paramei. 2008. Perception of Direction Changes in Animated Data Visualization. In *Proceedings of the 5th Symposium on Applied Perception in Graphics and Visualization (APGV '08)*. ACM, New York, NY, USA, 205. DOI: `http://dx.doi.org/10.1145/1394281.1394331`

[69] Alice Thudt, Uta Hinrichs, Samuel Huron, and Sheelagh Carpendale. 2018. Self-Reflection and Personal Physicalization Construction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, 1–13. DOI: `http://dx.doi.org/10.1145/3173574.3173728`

[70] Anna Vallgårda and Tomas Sokolar. 2010. Material Computing: Computing Materials. In *Proceedings of the 12th ACM International Conference Adjunct Papers on Ubiquitous Computing - Adjunct (UbiComp '10 Adjunct)*. ACM, New York, NY, USA, 383–384. DOI: `http://dx.doi.org/10.1145/1864431.1864447`

[71] Bruce N Walker, Amanda Nance, and Jeffrey Lindsay. 2006. Spearcons: Speech-based earcons improve navigation performance in auditory menus. In *Proceedings of the 12th International Conference on Auditory Display (ICAD 2006)*. Georgia Institute of Technology, 63–68.

[72] Bruce N Walker and Michael A Nees. 2011. Theory of sonification. In *The sonification handbook*. Logos Publishing House, Berlin, Germany, 9–39.

[73] Jordan Wirfs-Brock. 2019. Recipes for Breaking Data Free: Alternative Interactions for Experiencing Personal Data. In *Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion (DIS '19 Companion)*. ACM, New York, NY, USA, 325–330. DOI: `http://dx.doi.org/10.1145/3301019.3323892`

[74] KatieAnna Wolf and Rebecca Fiebrink. 2019. Toward Supporting End-User Design of Soundscape Sonifications. In *Proceedings of the 25th International Conference on Auditory Display (ICAD '19)*. Georgia Institute of Technology, 268–276. DOI: `http://dx.doi.org/10.21785/icad2019.046`

[75] Shamima Yasmin. 2017. Data Visualization versus Data Perception. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology (VRST '17)*. ACM, New York, NY, USA. DOI: `http://dx.doi.org/10.1145/3139131.3141226`

[76] Jack Zhao and Andrew Vande Moere. 2008. Embodiment in data sculpture: a model of the physical visualization of information. In *Proceedings of the 3rd international conference on Digital Interactive Media in Entertainment and Arts (DIMEA '08)*. ACM, 343–350. DOI:`http://dx.doi.org/10.1145/1413634.1413696`