Accountable Artefacts: the Case of the Carolan Guitar

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ABSTRACT
We explore how physical artefacts can be connected to digital records of where they have been, who they have encountered and what has happened to them, and how this can enhance their meaning and utility. We describe how a travelling technology probe in the form of an augmented acoustic guitar engaged users in a design conversation as it visited homes, studios, gigs, workshops and lessons, and how this revealed the diversity and utility of its digital record. We describe how this record was captured and flexibly mapped to the physical guitar and proxy artefacts. We contribute a conceptual framework for *accountable artefacts* that articulates how multiple and complex mappings between physical artefacts and their digital records may be created, appropriated, shared and interrogated to deliver accounts of provenance and use as well as methodological reflections on technology probes.

Author Keywords
Internet of Things; Digital Record; Physical Artefact; Guitar; Music; Technology Probe; Provenance; Archiving; Augmented Reality; Tangible and Embedded Interaction.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
We are entering a world in which everyday things become networked to create the Internet of Things [1]. Embedding sensing and communications into things promises to make them smart [34] and social [2], enabling new applications in logistics, healthcare and smart environments [24]. These networked things will generate digital records that reflect where they have been, who they have met and what happened to them. They may therefore serve as memory objects, helping us construct our identities and self-histories [50], or as narrative objects, enabling us to tell stories [43]. Their records will enhance their economic and social value [7], support provenance [44] and extend their utility [18].

HCI has begun to explore the opportunities and challenges of connecting everyday things to their digital records. The Tales of Things and Electronic Memory (TOTeM) project [7,48] deployed technology probes based on RFID, QR and Web technologies to reveal how scanning an object might replay its past associations, locations and the memories of its owners, and proposed novel applications such as enhancing the value of second hand goods through stories of prior use [17], an idea also explored in the Significant Objects project where narratives enhanced the value of goods on eBay [26]. An ethnographic study of the lives of war-gaming miniatures revealed the complex ways in which players captured and used digital records, often carefully documenting their making, recording their use in gameplay and telling stories afterwards [18].

Inspired by this previous research, we were motivated to further explore the nature and utility of the digital records of everyday things. Our distinctive focus has been on the rich nature and diverse uses of the digital records that are generated and shared as things *pass from person to person*. Like TOTeM, we have employed a technology probe [33], creating a unique augmented thing that could tour to diverse people and settings as part of an unfolding design conversation. In our case, this took the form of an acoustic guitar that was decorated with interactive inlaid patterns so that it could be scanned using a mobile device so as to access its history.

We offer three contributions from this work. First, we present the design and experience of our guitar as an example of the rich ways in which long-lived everyday things may be mapped to their digital records. Second, we draw on this example to derive the strong concept [30] of *accountable artefacts* – things that can be interrogated to deliver diverse accounts of their histories – so as to guide future study and design. Third, we draw out methodological implications of augmenting an everyday but valuable artefact with digital functionality as a technology probe.

A TOURING TECHNOLOGY PROBE
Our overarching approach has been one of Research Through Design [55] in which research findings emerge from processes of designing interactive systems and may be documented in an annotated portfolio [28]. Research Through Design has emerged as a broad umbrella under which one can find various specific methods ranging from cultural probes that capture inspirational materials in the early stages of design [29], to participatory approaches that engage users as design partners [49], to critical design

where provocative products challenge norms and foreground values and ethics [8,21]. We have adopted the method of technology probes. A technology probe is an "instrument [quite literally a musical instrument in our case] that is deployed to find out about the unknown – returning with useful or interesting data" [33]. A probe embodies a specific design idea, embedding inspiration *within* design rather than providing inspiration *for* design [23]. Hutchinson *et al* propose that technology probes balance three goals: the design goal of inspiring reflection on new technologies; the social scientific goal of understanding needs and desires; and the engineering goal of field-testing [33]. They maintain that a good probe is simple yet flexible, open-ended, adaptable, co-adaptive [38] (i.e., users can adapt it too) and gathers data.

The Carolan guitar

We have chosen to augment an acoustic guitar as a probe object. Acoustic guitars are played and owned by millions of people worldwide, are readily portable (rather than being installed in one setting) and can have long lifetimes, potentially spanning decades, during which they accrue rich stories, from personal memories of learning and performing to the widely reported histories of 'celebrity' instruments. Our probing proceeded in two phases. First, we engaged a luthier (a traditional instrument maker) to hand-make an acoustic guitar. Our aim was to create an unusual, valuable and functional instrument that people would naturally wish to host and play. We augmented our guitar by inlaying interactive decorative patterns into its woods that could be scanned using a mobile device in order to access its digital record. We chose an augmented reality technique called D-Touch in which computer-readable visual codes are embedded into the topology of images [13]. Previous research has applied this technique to handmade craft artefacts and suggested that it affords creative flexibility to visual designers [39]. It therefore appeared to be a good fit with our goal of hand-crafting an acoustic guitar. We gave our guitar a distinct identity and backstory in order to establish its uniqueness, naming it 'Carolan' in tribute to the legendary 18th century Irish harpist who was himself a nomadic performer and storyteller. We hired a graphic designer to create a series of interactive Celtic knot work designs that were then inlaid by our luthier (Figure 1). Finally, we implemented a mobile app to scan the patterns and trigger interactions, releasing this through Google Play and iTunes and updating it with new functionality in response to emerging ideas as the probing unfolded.

The second phase was to release Carolan into the wild, building up its digital record as it travelled. Our aim was to engage a diverse set of stakeholders in an inspirational design conversation, jointly exploring the nature and potential value of the guitar's digital record through a deliberately broad series of encounters in diverse settings. We followed a snowballing approach to recruitment, initially drawing on our own contacts with local players, venues and shops but then quickly reaching out through their contacts to engage people further afield, ultimately internationally. We progressed from early engagements where we accompanied Carolan on its travels so as to field-test the probe and seed its initial record to loaning the instrument for weeks at a time. Participants were encouraged to use the guitar as they wished. We then rapidly responded to their design ideas by reconfiguring our app. Participants and researchers jointly documented Carolan's history throughout its travels, capturing a corpus of photos, recordings, notes and interviews and drawing on these to create a series of blogposts (on carolanguitar.com).

SIX ENCOUNTERS WITH CAROLAN

Over a period of a year, Carolan travelled to 6 homes, was played at 3 gigs and 2 recording sessions, visited 8 clubs or jam sessions, hosted an 'open mic' event, resided in a shop and undertook an international road-trip. During this time 30 players contributed to its record, 8 being professional and 8 female. This produced over 100 video recordings, 5 studio audio recordings, and hundreds of photos that contributed to 50 blogposts. Participants responded enthusiastically to Carolan, although were mixed in their attitudes to its interactivity, ranging from those who immediately embraced the possibilities to those who were keen to experience the guitar itself but claimed little interest in digital technologies. In what follows, we distil this complex history into a series of six encounters that illustrate the nature and uses of its digital record in different settings.

In the luthier's workshop

We begin with the birth of our guitar in the luthier's workshop over a period of six months. We captured extensive documentation of this process including design sketches, photographs of the luthier at work, time-lapse videos of the front and back being laser etched and an official photoshoot. These were written up as a series of 23 blogposts constituting the initial digital record of the instrument from first concept through to a video of the luthier performing its first ever song {1-23}[1].

The build process involved specifying body size, shape and tonewoods {4, 8}; designing Celtic patterns {5}; and deciding which surfaces of the guitar to decorate {9}. We aimed to provide a flexible platform for exploring the creative possibilities of scanning the guitar and so choose to extensively decorate the instrument so as to provide multiple points of connection to its record, each with a distinct visibility and access. We eventually decorated six surfaces with distinct visual codes (Figure 1) the *headstock, front, back*, *top soundhole*, a small 'nook' in the *cutaway* underneath, and a *fretboard* marker at the 12th fret. The latter requires the strings to be removed before scanning.

Construction involved traditional processes of hand-crafting {21}, with some use of a laser cutter to prepare surfaces for inlay {14, 17}. The intricate inlay on the front led to the

[1] References in braces refer to posts on www.carolanguitar.com (verified January 2016) that provide additional documentation.

innovation of a removable soundhole on the top (being held in place by small magnets) to enable access to the inside {19}. We were inspired to create three further digital resources at this stage, configuring our app to attach them to different surfaces. A certificate with official details of the model, maker, birthdate and materials was attached to the headstock, conventionally home to the maker's logo. A user-guide explaining how to control the pickup inside the guitar was connected to the removable soundhole. A technical specification with details of internal structure (bracings and truss rod), electronics (pickup specification) and maintenance history was attached to the 12th fret.

Figure 1. Patterns applied to the front, top soundhole and fretboard (left), headstock (middle), back and cutaway (right)

At home

Carolan was hosted in 6 homes for a week at a time (revisiting one for a second week). Owning a handmade guitar, if only temporarily, was an extraordinary experience for amateur players, one that was greatly enhanced by viewing recordings of it being played by the professionals who had helped us seed the initial record (e.g. {27, 31, 35, 39, 48}). In turn, players were keen to record themselves, using the camera we provided to capture videos {45} (one player recorded over twenty). These were typically of a sketchy nature, capturing pieces they were learning or composing. Naturally, they were cautious about sharing these publicly, so the resulting collections, while extensive, assumed the character of personal archives of 'works in progress' to support their own reflection. Carolan visited regular clubs and jam sessions, where it was played by various attendees {25, 40}. Players also discovered the guitar's distinctive quirks (e.g., the gypsy-jazz style fret marker at the 10th fret rather than the more conventional 9th) leading us to extend the user-guide with 'playing tips'.

These experiences inspired us explore the idea of personalized mappings between Carolan and its digital record and we began to adapt the guitar's behaviour to each player it visited. We typically left the headstock, top soundhole and fretboard mappings unchanged, but reconfigured the front, back and cutaway patterns to map to personalized content such as curated playlists of existing recordings they might appreciate, links to their own websites and social media, and a personal archive of their own experience with Carolan. Some of these resources such as websites felt more suited to being attached to the public front of the instrument while others such as the private archive felt more suited to the hidden cutaway. Visits to regular clubs and sessions also inspired us to consider how these personalized mappings might dynamically adapt to location and time, for example recommending songs and tunes known to be popular at a given session.

Players evidently wished to keep in contact with Carolan once it had moved on, both to follow its future progress and to retain access to their own materials. We therefore created a series of interactive mementoes that could act as proxies for the guitar itself. These took the form of familiar guitar accessories that were decorated with Carolan's interactive patterns, including sets of plectrums, button badges and stickers (widely used to personalise instrument cases) {44}. We envisaged that these might also be distributed to friends who encountered Carolan, especially if they featured in its record. One player decorated his own guitar with a sticker, while a second, who felt a particularly strong affinity with Carolan, requested that we permanently painted our patterns onto an old acoustic guitar that he owned.

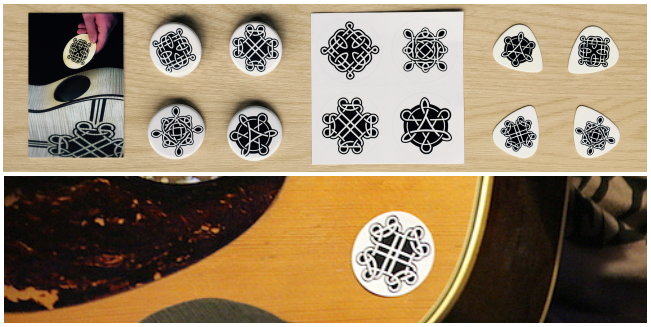

Figure 2. Early designs for interactive accessories

Writing and recording

Carolan joined a professional band at the early stages of composing a new album {43}. They used the guitar to record a sketch of a new song, contributing the original lyrics and chord sheet to its record. A second musician employed their week-long engagement with Carolan to compose a new instrumental, capturing multiple versions of the piece as it evolved. These players raised the idea of an instrument that passes among chains of musicians gathering songs for a new album. Inspired by this idea, we prototyped some interactive album artwork that could be inserted into a CD cover and that used Carolan's patterns to link to bonus materials such as early sketches of compositions.

We undertook two recording sessions with Carolan, the first using budget equipment in a home studio {38} and the second with a professional engineer using high-grade equipment in a recital hall {41}. These produced six polished audio recordings along with photo and video documentation. They also delivered extensive technical know-how about choices and placements of microphones, equalization and effects settings to best capture Carolan's distinctive voice that were added to the growing user guide.

Performing

Live performance is perhaps the most exciting and yet demanding of situations in which a musician plays their instrument. Carolan took part in public performances that contributed further data to its record. In one early case, a touring professional musician took the guitar onstage, played a piece on it and described its concept and history to the audience at some length {35}. This inspired us to consider how scanning and retrieving songs and stories from the digital record might be interleaved with live performance. We therefore staged an Open Mic session in which we invited six musicians to perform with Carolan while we in turn scanned it to conjure up and project videos during the breaks between performers {52}. In order to further engage the audience with scanning, we manufactured a set of decorated coasters that were left on tables around the venue. Scanning these revealed the programme for the show with links to performers' websites.

Learning

Several of those who hosted Carolan noted how it might support learning. A retailer who accommodated Carolan in their shop {29, 33}(and who recounted stories of unusual guitars they had bought and sold) stressed how their business involved selling tuition along with instruments, suggesting that the guitar might deliver video lessons and enable students to upload their responses. One player spoke at length about how their weekly lessons drew heavily on Internet videos and proposed that Carolan's codes could "point to the future" as well as the past, meaning that they might recommend videos to "take you to the next level". They speculated that the guitar might be enhanced with sensors to recognize what you were playing {50}.

We were therefore inspired to explore how Carolan might deliver tuition. Our discussions turned to how teachers often accompany their pupils during lessons. Not only might Carolan recommend new pieces to learn, but it might also play a second complementary part along with them. Inspired by Carolan's Celtic theme, we created some traditional Irish music lessons {51}. For each tune to be learned, we recruited musicians to record the melody as if playing in a traditional session. We then recorded a separate guitar accompaniment. We configured Carolan with three modes of scanning. Scanning the front triggered it to play a melody part, inviting the player to play along on the guitar (we chose the front with the idea that the player might mount a tablet on a music stand and sit facing it ready to play). Scanning the back played Carolan's accompaniment so that the player could study it in isolation or play along on another instrument. Finally, scanning the cutaway yielded the sheet music, chord charts and other notes. We envisaged that the same approach might enhance live performance with players dueting with themselves, especially if the scanning were integrated with live performance systems.

On the road

It is part and parcel of a guitar's life to be on the road, whether being carried in a gig bag to a local session or packed in a flight case and shipped between countries during touring. We equipped Carolan with two sensors to help document its travels: an Affectiva Q Sensor logged accelerometer and temperature data for thirty hours at a time, while a small Autographer camera automatically captured hundreds of photos, along with GPS coordinates, triggered by movement and light levels. Armed with these sensors and inspired by the popular narrative device of the roadtrip, we grasped the opportunity of exhibiting Carolan at a conference to document its first journey overseas, capturing encounters with new people and places including airline staff and passengers who readily recounted their own guitar stories {46, 47}. Mounting the camera inside Carolan delivered an unusual guitar-eye view of the world {49}, with the movement triggered camera often capturing images of people as they played and scanned the instrument (Fig. 3, left). We used these and other images to annotate movement and temperature data, creating a 'life-logging' visualisation of Carolan's end-to-end journey (Fig. 3, right).

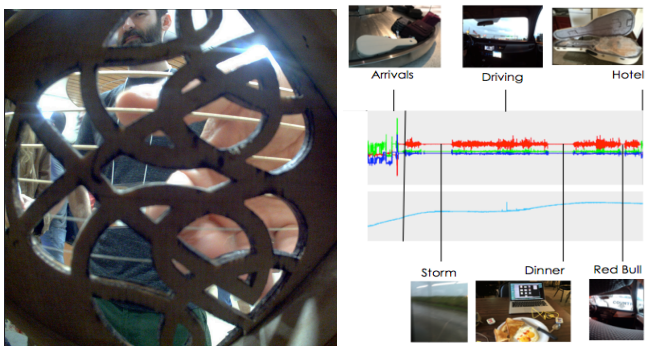

Figure 3: Capturing and visualizing Carolan's road trip

Sensor data offered insights into the stresses and strains experienced by a travelling instrument. The music press abounds with stories of damaged instruments along with travelling advice (e.g., the conundrum of whether to try to carry your instrument as hand-baggage or to check it into hold). Even when not travelling, concerns about how best to store an instrument have stimulated a market for custom humidity sensors and dehumidifiers. Carolan's sensors revealed moments of stress such as the temperature inside the case exceeding 40 degrees Celsius when it was left in the trunk of a car (fortunately without the guitar inside) as well as various jolts when being moved. This reminded us that the digital record might help address familiar Internet of Things concerns of security, safety and logistics.

Finally, our experience highlighted significant challenges for the automatic capture of images and sensor data. Automated cameras raise privacy concerns, especially when hidden inside an everyday object that enters private places such as hotel rooms and homes or sensitive ones such as airports. Airline regulations insist that devices powered by lithium-ion batteries are powered down when in the hold. Consequently, it was vital that Carolan's travelling companion retained control over when sensors were placed in the instrument and when they were collecting data.

MAPPING CAROLANS'S DIGITAL RECORD

We now draw on these six encounters to illustrate the nature and uses of Carolan's digital record. We reflect on the broad composition of the record, the uses to which it was put by different people, how it became flexibly connected to the instrument, how its reach was extended through proxy artefacts, and how it was captured.

Composition, users and uses of Carolan's record

Our experiences reveal how Carolan's broad digital record comprises five primary types of information:

- *Historical provenance* including certification of its maker, when and where it was made, sustainable sourcing of materials, maintenance log, and a documented history of ownership (including loans).
- *Personal and public archives* of performances, recordings, and compositions, documented as video, audio, lyric sheets and chord charts.
- *Historical and fictional stories* inspired by Carolan, including stories of other found, owned, lost, damaged and regained instruments that people recounted.
- *Documentation to support ongoing use* including an extended user guide (with playing and recording tips contributed by players), personal set-lists, playlists to be called up during live shows and materials for lessons.
- *Data pertaining to long-term wellbeing* including measurements of movements and environmental conditions during transportation and storage that might encourage good practice or account for any damage.

We have also seen how diverse stakeholders might share and contribute to this record. These include: makers and legal owners (ourselves); temporary owners (players); their friends and collaborators (at clubs and sessions); various technicians (from luthiers to recording engineers); teachers and learners; and audiences who encounter the instrument at performances. We have envisaged multiple ways in which the digital record might add value to how these stakeholders experience Carolan. Owners may enjoy a richer emotional attachment through the stories it can tell. Learners might summon up recordings to accompany them during practice or be recommended new exercises based on how they play. Makers can follow where their instruments go. Technicians can inspect the guitar to get detailed usage and maintenance information. In short, the digital record of an acoustic guitar is a complex beast spanning multiple forms of documentation, users and potential uses.

Connecting Carolan and its record

Our approach of decorating Carolan with six distinct interactive patterns led to an exploration of how it might best be connected to its digital record. A relatively complex artefact such as a guitar offers multiple surfaces as potential points of interaction that vary in their cultural meanings (the headstock is traditionally reserved for the maker's logo, the top sound-hole provides access to internal controls, the front might be thought of as the public voice) and availability to different audiences (the large back can be read from several meters away, the front and headstock require approaching close-up, the top sound-hole and nook require holding the instrument and turning it over, while scanning the fretboard requires the strings to be removed).

Carolan's encounters quickly revealed the need for multiple, dynamic, personalized and contextualized connections between these six surfaces and its digital record. We configured personalized mappings for individual players, adapting Carolan's playlist to their own interests and linking to their repertories. We configured event-based mappings for performances such as the Open Mic and task-based mappings for activities such as learning. As a result, we established some rules of thumb as to appropriate uses of Carolan's surfaces. Three retained more or less consistent 'canonical' uses throughout:

- The headstock remained linked to the instrument's official provenance (the maker's certificate and officially curated history on the public blog).
- The top sound-hole remained linked to the user-guide, though this might be personalized to particular users and tasks such as learning, performing or recording.
- The fretboard inlay under the strings remained linked to the technical specification and maintenance history.

The three remaining surfaces were employed more fluidly, though again with some general tendencies:

- The front was often adopted as the 'public voice' of the instrument, connecting to playlists of recordings.
- As a small intimate code, the nook tended to be associated with personal, hidden or bonus materials.
- The back has been treated as a somewhat general surface, being variously mapped to players' profiles, concert programmes and other supporting information.

A further question concerns who should make and control these connections? So far, we (as developers and owners) have made them for other people, but it seems likely that players would wish to control at least some aspects of mappings for themselves, for example setting up the guitar for a particular performance, lesson or recording session. We also note the possibility for players to specify the location and temporal characteristics of mappings so that they become applied or recommended at particular events.

Our final reflection on this topic concerns how scanning these connections might be more gracefully integrated with the situated use of the guitar. 'Looping' technologies already enable guitarists to play along with themselves live on stage, but demand flexible, reliable and discrete control (typically via foot pedals). How might we make Carolan's scanning more usable in a live setting?

Keeping in touch with Carolan

A striking and unanticipated practice that emerged during Carolan's travels was the fabrication of various physical mementoes that served as proxies for the guitar's actual presence. These were decorated with Carolan's knotwork

designs so that they could also be scanned to conjure up material from the digital record. Examples included plectrums, stickers, button badges, coasters, album inserts, and the more extreme case of permanently painting patterns onto another guitar. Such mementoes meet multiple needs:

- They enable people to maintain an emotional connection with the instrument once it has moved on. Players were keen to keep in touch with Carolan and one luthier reported a strong emotional attachment to his guitars, expressing a desire to follow their progress.
- They add value to albums and other musical products, for example drawing on Carolan's patterns and record to create interactive album artwork. This reflects previous accounts of how amateur musicians associate digital downloads with handcrafted physical artefacts so as to add value through personalization [32].
- Merchandise such as button badges enable fans to publicly display their affiliation while also promoting the instrument, its players and associated events.
- They extend the physical presence of the object, allowing it to be scanned at a distance, both spatially (an audience can scan coasters on tables if the guitar is not in view or is too far away) and temporally (when the instrument has left the venue).

Our choice of employing interactive decorative patterns is especially pertinent here as these are both publically visible and can be readily applied to many new artefacts. This said, other approaches such as embedded electronics might be used to the same effect.

Capturing Carolan's record

Our final reflection concerns how the digital record was captured. We experimented with various approaches from the use of off-the-shelf technologies such as video cameras to capture performances and both professional and amateur audio equipment to capture recording sessions, to less conventional technologies such as automated photography from inside the guitar and the use of movement and environmental sensors. This said, our approach throughout was largely manual. Participants were provided with a toolbox (actually a small suitcase) of devices and could choose how to best deploy them in a given situation. They/we then collated and curated the resulting material, uploading it to familiar and robust services such as Soundcloud and YouTube and writing a series of blogposts.

While this manual approach allowed us to easily engage participants in exploring the diverse nature of the digital record, various people commented on the potential for greater automation. The luthier who borrowed Carolan noted the difficulties of documenting the build process, raising concerns about the additional time required to capture and edit videos as well the risks of revealing to customers some of the 'messier' aspects of handcrafting, the rough and unfinished state of the instrument at some points and making mistakes. Similar concerns about balancing ease of capture with editorial control will apply to composing, performing and recording. Our engagement with music tuition also raised calls for greater automation, with participants suggesting that the guitar might analyse their playing and recommend new lessons. Finally, our deployments of sensors during roadtrips highlights the potential for Carolan to self-document its movements and stresses and strains for logistical purposes.

ACCOUNTABLE ARTEFACTS

So far, our discussion has been grounded in the specific example of the Carolan guitar. We now seek to generalise our findings beyond this unique case to consider potential implications for a far wider range of everyday things. This involves developing a general conceptual framework for reasoning about the complex connections that may exist between physical artefacts and their digital records. Our overarching concept is that of an ***accountable artefact*** – a 'thing' that becomes connected to an evolving digital record over its lifetime and that can be interrogated to reveal diverse accounts of its history and use. We anticipate a wide variety of such accounts, from those concerned with conventional IoT issues such as logistics, to practical guidance over usage and maintenance, to formally tracing provenance, to telling personal 'tales' of ownership [7].

We intend our framework to provide sensitising concepts [4] to guide future studies, attuning researchers to the kinds of digital records that artefacts might generate and their potential uses, while also providing a language for describing findings and relating them to the wider literature. We also intend our framework to help generate future designs. In the terms of Höök and Löwgren, our notion of an accountable artefact is therefore intended to be a *strong concept*, a form of intermediate design knowledge that carries a core design idea; bridges specific instances and generalized theory; addresses interactivity; speaks of use over time; and generates designs [30]. We now expand our overarching concept of an accountable artefact into a series of more specific concepts that express different aspects of how a 'thing' may be structured and connected to its digital record so as to deliver various kinds of account.

Physical artefacts and digital records

Our first group of concepts focuses on the structure of accountable artefacts. First there is an identifiable ***physical artefact***. Thus, our focus here is on material artefacts. Moreover, we are interested in artefacts that are readily identifiable as things, whose essential qualities, properties or characteristics give them an identifiable *haecceity*, i.e., sense of 'thisness' [25], making them worthy of a name and the responsibilities of ownership. We are especially interested in long-lived artefacts that may move between contexts and owners. We also note that such artefacts may have complex physical manifestations comprising multiple parts, including various components, accessories and even proxies that project their presence across space and time.

This physical artefact then becomes connected to a ***digital record*** that grows over its lifetime to potentially encompass

an extensive history of its making, maintenance, ownership, use and travels. Just as people generate digital footprints as they use computers, browse the Internet and carry or wear sensors [47], so this digital record may include logs of digital interactions alongside location, environmental and other contextual data. However, it may also include user-generated documentation arising from making, maintenance and use, including social media generated by those who encounter it. This broad digital record may be captured though a combination of automated and manual means, though given the goal of creating narrative 'tales' and the privacy concerns that may arise when the artefact enters new and possibly unforeseen contexts, we anticipate a high degree of human involvement in its capture and curation.

Mappings

Having laid some groundwork, we now turn to the essence of accountable artefacts, the notion of ***mappings*** between the physical artefact and its digital record that configure it to deliver different accounts. We stress two key aspects of mappings. First, as we saw with the Carolan guitar, *multiple mappings* may be created over the artefact's lifetime as it is owned by different people, travels to various places and is used in diverse ways. Thus, it is the choice of mapping that yields a particular account when the artefact is interrogated (e.g., is scanned). Second, each individual mapping comprises a *bundle of links*, each connecting a facet of the artefact to a facet of its digital record (Figure 4). Thinking in terms of bundles of links is important because it allows a given mapping to support complex uses or address different stakeholders who may be present in a given context. Thus, Carolan can be given a distinct mapping for each performance, home visit, music lesson or writing session with its six links variously targeting players, audiences, owners, and technicians who may be present in each.

We can draw on Bieber *et al*'s survey of hypermedia to help clarify some key properties of individual links [6]. Like augmented reality systems in general, our links tend to be *transclusive* [41], bringing digital information to the physical artefact, rather than navigating the user away from the artefact to some new thing. As in Carolan's case, they may often be *unidirectional*, linking from the physical artefact to its digital record but not vice versa. This said, we note some intriguing possibilities for linking the other way: perhaps following a link from the digital record could summon the physical artefact or even trigger the fabrication of a new physical proxy? Support for multiple mappings suggests that bundles of links will be maintained in external *linkbases* rather than being *embedded* [31]. Finally, link *anchors* may be physically manifested on the artefact. In such cases, the form of a physical artefact both affords and constrains possibilities for interaction while also conveying semantic and cultural meaning [40]. In particular, designers need to account for the visibility and accessibility of different surfaces at varying degrees of intimacy. Some are visible at a distance, others only when standing nearby, others when holding the artefact, and yet others when opening it up or removing parts of it. They also need to reflect on their cultural associations, for example the front of the artefact being its public face. The need for a principled mapping of surfaces to anchors is readily apparent when following the augmented reality approach of visibly decorating the artefact with interactive patterns. However, the same issues are likely to apply no matter what technologies are employed, for example when embedding electronic tags into an artefact.

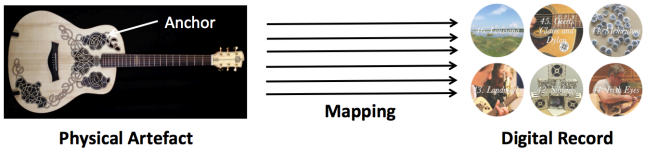

Figure 4. Physical artefacts, digital records, mapping and links

Appropriation

Our second group of concepts addresses how accountable artefacts evolve through various processes of appropriation. The idea that users appropriate technologies, adapting them to their specific needs and contexts, has been discussed widely in HCI. Dourish notes how people adopt and adapt technologies during the course of practice [20] in order to bridge Ackerman's social-technical gap [3]. Carroll *et al* propose a model in which processes of appropriation, non-appropriation and disappropriation move technologies between being designed, in-use and rejected [12]. Rather than seeing appropriation as a sign of technological failure, Dix celebrates it as supporting situatedness, dynamics and ownership, and offers guidelines to design for appropriation including: provide visibility, aim to support rather then control, encourage sharing and learning from appropriation, and enable plugability and control [15].

Following Dix, we propose that it is important to design accountable artefacts for appropriation so that they can be adapted for diverse owners, uses and contexts over their lifetimes. We therefore introduce two further concepts to deal with different kinds of appropriation. ***Digital appropriation*** involves changing an existing mapping so that some of its links reconnect to alternative facets of the digital record (e.g. configuring the front of Carolan to point at new playlists for various performances, lessons and home visits). In contrast, ***physical appropriation*** involves creating proxy physical artefacts (e.g., Carolan's plectrums, badges, stickers, CD inserts and so forth) that then connect back to the digital record. Both these forms of appropriation require support for Dix's notions of interpretation, visibility, sharing and plugability. For digital appropriation, it should be easy to add new content to the digital record (e.g., through social media), inspect an existing mapping to see its current links, and then alter these to point at this new content. For physical appropriation, it should be possible to reapply existing anchors to new artefacts, for example acquiring Carolan's existing patterns and applying them to new things. In turn, all of this requires being able to share mappings among a community of users, including support

for recursive appropriation in which derived mappings are themselves appropriated to create yet more mappings.

From owners to custodians

Our final group of concepts addresses the question of ownership. There is a growing literature in HCI around notions ownership, especially with regard to the curation of digital possessions and personal identity, for example digital photos in the home [14], social media profiles [54], teenagers' virtual possessions [42] and the Web as a personal archive [36]. Our experience with the Carolan guitar suggests that we need to extend these notions of possession and curation with new concepts that reflect the complex lives of long-lived and valuable artefacts.

We introduce the concept of ***custodians*** to encompass the diverse stakeholders that might take responsibility for an accountable artefact, including its digital record. These may include its original makers, a succession of legal owners, but also those who assume temporary custodianship (e.g., borrowing the artefact).

Then there are the custodians of the mappings themselves – those who have at some point configured the artefact to yield a particular account when interrogated. Each new mapping should have an identifiable custodian, responsible for maintaining its links over time. Inspired by the approach of trajectories through experiences [10] and subsequent proposals that this thinking should be applied to designing the trajectories of everyday things [18], we propose that the custodian of a mapping might dynamically update it to design ***encounters*** with the artefact, configuring it to deliver distinct information before, during and after meeting an individual or entering a context. For example, Carolan was configured to deliver different information before, during and after its Open Mic performance.

The custodians of mappings can influence appropriation through two final concepts. First, they can specify the ***mutability*** of each of link, meaning whether this link can be pointed at new content when the mapping is appropriated or whether it remains fixed. Thus, the original maker of Carolan might set up a mapping where the headstock is immutably linked to their maker's certificate but where other surfaces can be freely remapped. A subsequent legal owner may further appropriate this in a new mapping that ensures that the back always points to their personal information in case of loss or theft, while leaving the remaining surfaces free to be appropriated by players, venues and other more temporary custodians.

Our final concept, ***acknowledgement***, is intended to ensure that the custodian of a mapping derives benefit from its appropriation. First, they may be credited for their contribution through something akin to a Creative Commons license. Second, a mapping may be inspected to reveal the chain of 'upstream' mappings from which it was derived, back to an original source mapping. Finally, they might harvest usage data from appropriated mappings, collecting information about where the artefact has gone and who has interacted with it. For example, the original maker of the artefact might be notified of subsequent transitions of legal ownership as part of a product registration scheme, while the current legal owner might keep in touch with the artefact when loaned to others. This notion of harvesting data from derived mappings reflects the findings of a study of amateur musicians that revealed how they were often happy to distribute their material freely in return for feedback and connections to fans, but often struggled to capture this feedback [32].

Figure 5 summarises the processes of recursive physical and/or digital appropriation supported by the further concepts of mutability and acknowledgement.

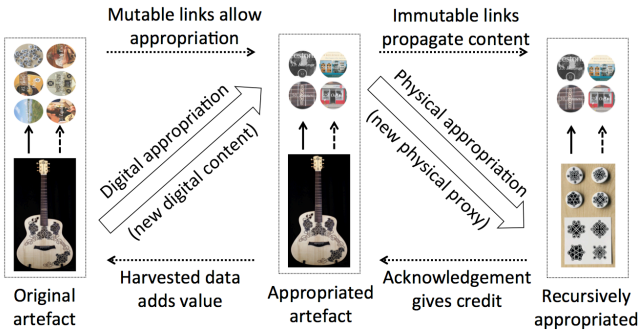

Figure 5. Physical and digital appropriation

These concepts of mutability and acknowledgement raise one final question. Where do mappings actually live in practice and what authority controls how they are appropriated? Schemes such as ours imply controls on digital copying that can be notoriously difficult to enforce in practice, especially in an age in which digital (and increasingly physical) copying is widely practiced as part of a 'remix' culture [35]. We therefore identify one final form of custodianship to be considered when designing accountable artefacts – responsibility for storing and enforcing mappings. This might be achieved in various ways, from reliance on legal authorities to register contracts of ownership and responsibility (think of houses and cars), to added-value commercial services provided by makers and retailers, to people voluntarily signing-up to fair and appropriate use under Creative Commons. We also note the possibility of physically embedding an initial mapping and digital record into the physical artefact itself at the point of creation as an immutable baseline that always travels with the artefact and from which other more flexible mappings can be appropriated.

PUTTING OUR CONCEPTS TO WORK

In line with Höök and Löwgren's proposal for *strong concepts* [30], we now explore how our notion of accountable artefacts might help generate new designs. Many everyday things meet our broad criteria for being accountable artefacts (identifiable, valuable, long-lived, passing among multiple custodians, generating rich digital

records), from collectible antiques and artworks to cars and houses. Our concepts suggest various ways in which these might be enhanced through richer connections to their digital records.

Provenance. The first concerns authenticating the provenance of products, meaning their chronology of origination, ownership, alteration and use. Although originating in the world of historical art and antiquities, the notion of provenance has since spread to many fields, and through e-Science has been applied to the attribution of data in databases and trust on the Web [37]. The Open Provenance Model and standard [52] embeds concepts of usage, generation, derivation and association into provenance-graphs [53]. HCI research has explored how scientists understand such graphs [19], the provenance of design [44] and whether the public can engage with provenance concepts [5]. Our concepts support provenance in two ways. First, mappings connect artefacts to their digital records, making it easier to access provenance documentation. Second, our concept of appropriation with mutability and acknowledgement addresses the provenance notion of derivation and enables people to establish provenance graphs as an assertion made about provenance in a given mapping (e.g., claim to ownership) can be tracked back through a chain of mappings to a source.

Storytelling. Our concepts allow people to associate their artefacts with rich stories, from recollections that transform them into memory objects [50] to creative fictions [43]. Our concepts draw attention to the storytelling potential inherent in travelling artefacts in which 'road-trip' narratives provide the muse for new compositions or inspire chain-narratives as they pass among people and places (e.g., [22]). We also note how the performativity of an artefact may be enhanced by recalling recordings during live use. The open and flexible sharing and appropriation of mappings among custodians is key to these kinds of creative storytelling.

Servicing. Our concepts support the management and servicing of complex artefacts such as cars and houses where multiple custodians (e.g., the maker, owner, local garage and insurer for a car) will negotiate access to digital records. Our notions of multiple mappings with ownership and mutability offer a framework for reasoning about how such records are shared, retained or passed on by various parties as the artefact is used and changes ownership.

Collecting. There is a trend in the guitar industry for releasing collectable, limited-edition, celebrity-endorsed instruments that command high prices. This inspires a final idea to create limited-edition collections of artefacts that gain in value by sharing elements of a common history. Each artefact in the collection would come with an initial mapping to a shared history. Its custodian would be free to appropriate some links for their own purposes, while others would immutably connect to maker's documentation as well as regular updates from the original celebrity artefact. Local custodians would be able to share their own updates to create a wider social network of connected things.

Archiving. The cultural sector and especially museums and galleries have a longstanding interest in preservation and archiving. Recent writing in Science and Technology Studies has stressed the increasingly social, emergent and reflexive nature of contemporary archives that are becoming open to interpretation by diverse audiences [51]. These writings also stress the performative nature of archives, meaning the ways in which they are brought to life and iteratively developed through various social performative practices. Our framework might provide archivists with concepts for exploring how archives can be further opened up to more iterative, emergent, appropriated and performed mappings between preserved artefacts and their records.

A reference implementation

We we are aware of the notorious difficulty of translating HCI concepts into practice [45]. We have therefore produced a reference implementation of our framework in the form of an app called Artcodes that enables people to create, share and appropriate mappings between physical artefacts and their digital records and that is freely available on both iTunes and Google Play. Artcodes empowers users to create their own recognizable patterns (following the D-Touch approach) that they can then apply to their own artefacts so as to link them to web resources. The app includes an editor for creating mappings with multiple links. This supports digital appropriation through the editing of existing mappings and physical appropriation by reapplying existing decorative patterns to new artefacts. Implementations of mutability and acknowledgement allow custodians to manage how mappings are appropriated.

METHODOLOGICAL REFLECTIONS

We finish with some methodological reflections on our particular interpretation of technology probes. Perhaps the most striking aspect of this has been to create a travelling probe whose functionality has been improvised and extended as it has toured among different participants and contexts. Our choice of a handmade guitar was significant here. An acoustic guitar is *portable*, being easily transported to different users and settings and installed with minimal fuss. It balances *niche interest*, appealing to knowledgeable and enthusiastic users who are keen to host it and able to venture design suggestions, with being *democratic* in the sense that many people can play it to some extent and many more understand and may appreciate it. Our handmade guitar is *valuable* (costing us several thousand dollars to build), which piques curiosity and motivates people to host it and show it to their friends. It is however, actually rather *durable*, allowing us to engage users over the course of a year and potentially being available for years to come. Finally, our choice of decorating an acoustic guitar is *provocative*, not in a critical design sense [16], but because such extensive and visible

application of digital technology to a traditional instrument raises eyebrows among players and makers.

While the guitar itself was stable, its associated digital record and mappings were far more fluid, rapidly evolving in response to its travels. We adopted an improvisational approach to generating the digital record and connecting it to instrument. First, we provided users with a kit of off-the-shelf accessories (tablets and cameras) to support documentation {34}. Thus, the physical manifestation of our probe (guitar and accessories) comprised robust and familiar technologies, facilitating flexibly improvisation by users with minimal intervention from us. Second, we evolved our app to dynamically edit and publish new mappings as described above, allowing us to extend interactions with the guitar remotely and on-the-fly. This separation between a stable and robust physical probe kit and remotely improvised digital interactions enabled us to respond rapidly to users' ideas as our probe travelled.

Finally, we reflect on the nature of users' engagements with Carolan. Over the course of our probing we transitioned from shepherded encounters, intended to seed an initial record with interesting materials, to more 'wild' encounters in which Carolan spent longer periods living in diverse settings. Players' evident knowledge of guitars and skill at playing them tended to place them on an equal footing with researchers in the design conversation, while seeing public documentation of previous engagements in the record enabled them to respond to and build on others' ideas. We suggest that, as a result, our probe was good at inspiring new ideas. Conversely, these engagements were less ethnographic or evaluative in nature, neither capturing rich materials about situated everyday use nor critically and objectively testing emerging designs. We would broadly characterize the nature of our engagement with users as being an iterative 'design conversation' in which a chain of users and designers positively engaged with the concept of a digital record, proposing many new ideas.

Looking back at Hutchinson *et al*'s three initial goals for technology probes [33], we suggest that our approach emphasises the design goal of inspiring reflection over the social scientific goal of understanding real-world use. Their third-goal was to field-test new technologies, with the suggestion that probes are not prototypes. Here, we argue for a more nuanced interpretation in which an adaptable travelling probe offers rich possibilities to transition from early prototyping to field-testing over its lifetime. What began with a prototype guitar ended up with the public release of a functional and tested app. Perhaps Carolan might even be further adapted to become a more ethnographic or evaluative probe in future years?

CONCLUSIONS AND FUTURE WORK

By deploying the Carolan guitar as a travelling technology probe we have revealed the complex relationships between things and their digital records, leading us to propose the strong concept of accountable artefacts:

- An ***accountable artefact*** comprises a ***physical artefact*** and ***digital record*** that grows over its lifetime.
- These become connected via multiple ***mappings***, each providing a specific account of the artefact for particular people in a given context. Each mapping comprises multiple *links* that connect a facet of the physical artefact to a facet of its digital record.
- Mappings can be created through recursive processes of ***digital appropriation*** that involves relinking an existing physical artefact to new aspects of its digital record and ***physical appropriation*** that involves making new physical proxies that project the presence of the artefact across space and time.
- Mappings are associated with identified ***custodians*** who can control the ***mutability*** of their links so as to preserve some aspects of the original mapping. In turn, appropriate mappings, ***acknowledge*** their source, sharing credit and possibly helping harvest usage data.

We have proposed various ways in which these concepts might prove useful in designing future interactive products including enhancing provenance, enabling creative collaborations and producing limited-edition collectibles.

We finish by noting two key caveats that suggest directions for further research. First, we recognize that Carolan is an unusual thing and moreover, is one with a relatively high financial value. It is an open question as to how our findings and framework will generalise to other kinds of artefact, including more mundane ones with a lesser financial value (or whose value lies in other areas such as personal meaning or utility) as well as more socially or culturally provocative ones. Second, as noted earlier, engagement with Carolan tended to be largely creative and constructive, centred around a series of 'forward looking' design conversations. Other kinds of artefacts, mundane or provocative, might reveal more of the problems and challenges associated with our approach. Thus, we are careful to position Carolan as an early probe into this space that sits somewhere between the mundane and provocative and that has served to inspire new ideas. We hope that this will stimulate further work to explore associations between a richer diversity of things and their digital records.

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