Audio Technology and Mobile Human Computer Interaction:

From Space and Place, to Social Media, Music, Composition and Creation

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ABSTRACT

Audio-based mobile technology is opening up a range of new interactive possibilities. This paper brings some of those possibilities to light by offering a range of perspectives based in this area. It is not only the technical systems that are developing, but novel approaches to the design and understanding of audio-based mobile systems are evolving to offer new perspectives on interaction and design and support such systems to be applied in areas, such as the humanities.

KEYWORDS

Design, Ethnography, HCI, Humanities, Interaction, Location, Mobile

1. INTRODUCTION

This article represents a series of research projects and approaches, which expand upon an initial workshop, "Audio in Place" that took place in 2016 (Chamberlain et al., 2016). The key theme of the workshop was audio and its relationship to mobile HCI (Human-Computer Interaction). The approach of the workshop was not to restrict submissions to one particular area, but to encourage papers from a multiplicity of domains. The research presented in this paper aims to extend our understandings of audio-based mobile HCI, provide a platform for discussion and debate, extending our understandings of mobile HCI and encouraging approaches to understanding technology that are at the forefront of Mobile HCI.

Mobile devices (in particular smartphones) as often stated, are now commonplace, affordable and used by large amounts of people on a global scale. Their portability, adaptability and 'always on' capability mean that they are often the "go to" technology for developing, testing and researching geo-locative interactive systems. However, recently there has been a growth in even more affordable

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technologies, systems such as the Arduino and BeagleBone, are but two of the many small form-factor hardware systems available. Often these systems are adaptable, are easily repurposed and can be used in conjunction with other existing technologies making them an attractive proposition for people wanting to develop portable exploratory audio-based systems. For a fuller exposition see McPherson et al. (2016) and Moreale et al. (2017).

However, the technology is only one part of the story, being able to take technology out into the world opens up a plethora of interactive possibilities, different ways to understand and interact with one's surroundings, new ways to interact with each other and the chance to develop different approaches to understand such interactions. Of course, the work in this article primarily focuses upon audio interaction, but still, in doing it has enabled people offer a wide range of perspectives that range from autoethnographic methods (Eslambolchilar et al., 2016) for mobile system design, through to location-based interaction, and design approaches that use the past as way to design, re-imagine and develop technologies today (De Roure et al., 2016a).

2. RECORDING SOUNDS, MAKING MEANINGS

In 'Acoustic Territories' (2010), LaBelle makes a case for understanding sounds as part of a "charged spatiality" (xviii); a social and emotional topology implicated in the emergence of a sense (- and politics) of place. Sounds, LaBelle suggests, are never private, but must be understood as a relational force that somehow weaves a space together while at the same time 'unhinging' it in unforeseen ways by associations, forming personal memories and emotions but also networks of social connections, cultural meanings and so on. In this section, we suggest that in order to imagine and build mobile interactions around localized sound, we need methods to address the opportunities in this field and that are attentive to the possible emotional and subjective values inscribed in the consumption as well as production of localized sound.

As such it suggests that practices of sound recording on mobile devices (as well as the ensuing use of recorded sounds for the purposes of distributing, sharing or mapping) offers relatively untapped modes of engagement. Particularly as both urban and rural architectures, infrastructures and mobile digital medias are becoming intertwined to form meaning and experiences (under the general motifs of ubiquitous computing, Internet of Things, or ambient intelligence), we see a need for methods that can help in exploring some of the possible ways in which tangible places and 'intangible' content such as sound can interact. Beyond (or arguably before) any technical challenges associated with building accessible and easy to use systems to allow people to record and share sounds using a mobile device, comes the question what values such systems might fulfil or what purposes they might serve.

We suggest that autoethnographies can play a part in an effort to connect sound recording to mobile HCI. Specifically, we explore possible connections between digital media, space and 'meaning making', suggesting how autoethnographies (Bødker and Chamberlain, 2016) might help in discovering and articulating design opportunities in the merging of mobile digital devices and meaningful place making practices.

3. AUTOETHNOGRAPHY

Using an auto-ethnographically inspired design approach to locate media goes beyond the conventional "implications for design" (Button, 2000), is more than a "scenic" study (Dourish, 2006), or an 'imposed' analytic. We suggest that it can be used as method of imagination, as a lens through which we can discover social as well as personal potentials in design. It can be associated with a self-design agenda … that focuses on the potential of self-experience and articulation for the designers work.

Autoethnographies are 'personal' accounts of cultural experiences. They rely on the ability of the ethnographer to reflectively connect an autobiographical account with broader cultural formations (Ellis, 2000). As autobiographical renderings, they are particularly open to 'vulnerable' narratives,

narratives that favour emotional and affective encounters with ourselves engaged in the world. As a method, we find that writing narratives in the style of an autoethnography are capable of teasing out significant and emotionally poignant stories and loose implications that are otherwise difficult to recount. They are ways of seeing ourselves engaged in a culture, and as such they can be ways of recognizing (and rendering) experiences that have particular emotional resonances or strong, embodied and affective impacts that traditional 'analytical' ethnographies (or indeed other methods) may neither be receptive to nor have access to.

Consider for instance how a workshop participant (*M*) recounts a particular sound that triggers a surge of nostalgia and visceral memory:

In my imagination the sounds affix themselves more readily to a broader childhood landscape of flat, overcast marshlands. Maybe driving through it, sitting in the backseat of my parents' car, or to the repetitiveness of the wet landscape?

He wishes that the sound:

… could seep out of the ground there too, that other people might share in my experience of the short musical sequence in what has, for me, become the 'proper' setting. Perhaps the music is also meaningful to other people?

The imagined connection of a sound with a place is arguably private, but experiencing such connections between sound and place can be positively communal, a notion deliberated in Truax' work on what he calls 'acoustic communities' (Truax, 2001). Communal sounds "are usually acoustically rich and may even have musical value, and therefore they acquire their significance in the soundscape through their ability to make a strong imprint on the mind, an imprint that embodies the entire context of the community". *M*'s rendering of the emotional effect of a sound seems private at first, but later points to the possibility of sounds as part of a shared process of making meaning.

Another narrative suggests how another workshop participant, wanted to share a significant sonic experience with other people:

I know it's odd but I'd like to share those kinds of things about the place that I live now. Just leave an audio trail, a story or a thought that people might come across in the ether. There's a Celtic hill fort next to the town that we walk over and I'd like to leave things for other people that I know to respond to, I have plans to use the defenses of the fort, they are layered like giant steps designed by some ancient architect.

Sounds emplaced and localizable in the landscape, as imagined in the above example, might come to work as traces of an emergent heritage landscape, part of an ongoing engagement in remembering or making sense of place.

Autoethnography, as an example of a highly self-reflective and emotionally charged approach, is a method that seems more personally relevant than those typically associated with more system-based design approaches. Traditional methods are less sensitive to the ways that the fleeting sense of listening and the ensuing emotions, sense of relationships, belonging, memory and meaning come together. Our method relates to the way that we, personally, imagine the potentials of what might fall under more technical terms such as "field recording" and "localized media" on mobile devices to represent and develop memory-scapes in respect to the way that we experience the world around us. In this way, the method supports a process of self-design where the gap between personal reflections, emotions or desires and design can be narrowed.

A number of tools of varying complexity exist to drive rapid experimentation with the concepts that emerge from autoethnographies. Using little-bits (www.littlebits.cc), small wearable and mobile prototypes that include sound and a variety of wireless sensors can be built. Raspberry Pi mini-computers (https://www.raspberrypi.org) can be used to build sound streaming devices (e.g. those often used for the locusonus soundmap, see http://locusonus.org/soundmap/051/). Recho (http://www.recho.org), a commercial iPhone app, allows users to leave behind short sounds tied to a location. Percussa Audio Cubes (https://www.percussa.com/what-are-audiocubes/) that allow a user to tangibly interact with different sounds. We have used audio cubes in workshops to facilitate discussions about sound, tangible interaction and mapping.

Further, we might supplement the standard autoethnographic medium (writing) with more focused renderings of the experience of field recording or consuming location-based sounds on mobile devices. This may point to further alternative ways in which users of mobile devices can 'tune in' to places and generate new collective and emergent meanings in place.

4. MUSICAL LANDSCAPES: FORMING RELATIONSHIPS BETWEEN THE PHYSICAL AND DIGITAL

'Locative media' originated in an effort to distinguish the emerging body of creative work undertaken with new mobile technologies from the commercial impetus of location-based services (Tuters 2004). There are numerous examples of locative media experiences that explore a range of digital interactions, such as: augmented reality, where digital media is overlaid. We now turn our attention to locative media, with a specific focus on locative music. The term onto the real world (Izadi et al. 2002; Vlahakis et al. 2002; Zimmermann and Lorenz 2005; Gildersleeve 2015); mediascapes, a term coined by HP Labs to describe site specific locative experiences, as authored by their Mscape tool (Behrendt 2005; Reid et al. 2005); context-aware, often used to describe works where a range of contextual data is used other than purely positioning technologies (Yu et al. 2008; Elliott and Tomlinson 2006; Abowd et al. 1996); mixed-reality, to describe the combination of real-world activity combined with online activity (Benford and Giannachi 2011; Crabtree et al. 2004; Galani 2003; Flintham et al. 2003) and specifically in relation to location-based games, the term pervasive games (Benford et al. 2003; Chamberlain et al. 2010; Waern, Montola, and Stenros 2009).

'Mapping' constitutes the central function of most locative media experiences, "making data geographically specific or placing a digital object in space" (Hemment 2006, 350). The latter half of this quote acknowledges Frauke Brehendt's placed sound experiences – a class from her taxonomy of mobile music (Behrendt 2010). Placed sounds describe the triggering of digital audio at predefined locales, typically realised via GPS positioning and GPS enabled mobile devices. Early adopters of these technological developments (i.e. Rueb 2002; Kirisits et al. 2008; Tanaka 2008; Blistein 2015; Collier 2015; Gaye et al. 2006; Bryan-Kinns et al. 2009; Reid et al. 2005; Chamberlain et al. 2010; Benford et al. 2003) were "asking what can be experienced now that could not be experienced before … a new understanding of the relation between physical and digital" (Hemment 2006). These practitioners noted that placing new, novel audio experiences into spaces functioned as a producer of content and also a stage upon which the content is delivered (Tanaka 2008).

In this section, we place a specific focus on forming relationships between physical space and the construction of digital musical soundtracks; proposing that the physical assembly of a chosen location with all is naturally occurring and built artefacts can serve as a structural blueprint from which a music composition can be created and placed. We draw upon a key example to illustrate this approach, as presented in the following.

We use an example of a large-scale musical soundtrack to accompany visitors at The Yorkshire Sculpture Park, North Yorkshire, in the United Kingdom, as charted in (Hazzard, Benford, and Burnett 2015; Hazzard et al. 2015). The Yorkshire Sculpture Park is a cultural heritage park set in the Yorkshire countryside. It is formed from a range of diverse and distinct landscaping, from formal gardens to open parkland. Sculpture exhibits are distributed throughout the park and visitors are free to roam, explore and interact with them in their own time. This soundtrack was a GPS driven experience using smart phones and headphones, where a soundtrack was composed and presented via a large number of musical cells and layers that could be triggered by GPS as visitors explored the park to create one single continuous musical arrangement. Original music was used throughout, composed specifically for the experience. The intention of the soundtrack was similar to that of the film soundtrack, whose role is to provide a supportive accompaniment, to reflect the narrative rather than dominate it.

In order to compose music for such a large location, with indeterminate duration and non-linear arrangement (i.e. dependent on the route and walking pace of each visitor) a coherent method to structure the music was necessitated. To achieve this we sought to establish relationships between the physical attributes of the park and key musical and features in the soundtrack. Scrutinizing the park revealed the following key attributes: (1) sculpture exhibits paced in specific locales; (2) a patchwork of physical regions demarcated by transitions in landscaping (e.g. formal gardens to expanses of grassed areas to rolling fields to constrained paths); (3) the placement of walkways, hedgerows and trees; and (4) finally buildings. This three dimensional assembly of interconnected physical attributes was used to directly structure the soundtracks musical features, at a high and at a low level.

First, we describe the high-level approach, termed musical landscapes. One of the main attributes of the park was this patchwork of physical regions made distinct by different types of landscaping and attributes that bounded them. In response our soundtrack was formed from a series of musical sections, or movements, overlaid directly onto this patchwork structure. Thus, a distinct musical section was heard within the bounds of each physical region. Figure 1 marks the collection of regions, as illustrated by different blocks of colour that spanned the park. The white areas in Figure 1 represent the location of sculpture exhibits. In practice, the boundary lines of these regions acted as GPS trigger zones, so a visitor's transition across boundary line is accompanied by a transition from the currently playing musical section to that new region's musical section. The rationale for the size and shape of these regions alongside the placement of neighbouring boundary lines can be described in four ways:

Figure 1. Musical Landscapes - patchwork of regions with key centre's marked

- **Constrained boundaries:** Drawn in reference to fixed physical structures that impede the user access, i.e., wall, fences, hedgerows, buildings, area that a user cannot cross;
- **Implied boundaries:** Drawn in reference to physical attributes such as structures or objects that can be traversed, but imply a transition, i.e., gates, changes of landscape such as formal gardens into rural parkland or from grassed areas onto concrete walkway;
- **Negotiated boundaries:** Boundaries are not defined by any physical structure, but rather in response, or negotiation to another adjacent negotiated boundary;
- **Unconstrained boundaries:** Not drawn to any physical attribute or in relation to any other boundary.

The majority of the regions are formed by ‘implied’ boundary types, thus defined in response to existing physical attributes.

From a musical perspective, a set of compositional techniques were then used to render each musical section distinct, especially those with neighbouring regions. Each section was composed in a different but complementary key centre (see Figure 2), new thematic ideas were employed within each region, alongside distinct musical textures (i.e. combination of instrument sounds). This meant that as visitors walked over these physical transitions they were similarly accompanied by musical transitions.

With musical landscapes depicting our high level musical structure – transitions between sections – we then considered a lower level of musical interaction that takes place within the regions themselves. Specifically, how to accompany with music a visitor’s trajectory into and out of interaction with sculpture exhibits. We termed this process, musical trajectories. We drew inspiration from Fosh et al., (Fosh et al., 2013) who’s ‘trajectory of interaction’ urges designers of such visitor experiences to contemplate four key phases of interaction with artefacts or points of interest, namely approach, arrive, engage and depart. In reply to this, we composed musical interactions for our regions that followed these four phases. Figure 2 updates our illustration to show a number of additional trigger zones placed with the majority of the regions. Typically, they fan out from the location of the sculpture exhibits to

Figure 2. Musical trajectories through regions

the outer boundary of a region. Each of these 'internal' trigger zones enact a further adjustment to the music played in that region. The following describes our musical approach:

- **Approach:** As a visitor walks towards a sculpture they anticipate the forthcoming interaction; consequently, music was composed to foreshadowed the moment of arrival by gradually increasing the musical intensity (i.e. crescendo) upon entry into each successive trigger zone;
- **Arrive:** This crescendo is then resolved at the moment of arrival (entry into a final trigger zone encompassing an exhibit). Resolution is typically enacted by a key change and a final push of musical dynamic;
- **Engage:** The moment of arrival then quickly gives way to a reduction of musical intensity and activity to provide space for the visitor to interact with the exhibit without distraction;
- **Depart:** As visitors withdraw from the exhibit and head back out through the trigger zones a different musical treatment is presented, one that maintains a low level of musical activity to prepare the visitor for the next approach phase encountered.

The techniques of musical landscapes and music trajectories enabled for the design, composition and authoring of a locative musical experience that exhibits close and intertwined relationships between the physical and the digital. The flow through the physical park is synchronised with the course of the accompanying soundtrack, at both a high and low level of musical detail. This approach enabled us to consider the physical form of the park in a new light whilst gracefully guiding and integrating a coherent structure into the composition of a large-scale musical work. We have not entered into discussion regards the experiential impact of music or audio when placed upon artefacts, or locales. Rather, we explored how multiple fragments of digital audio can be composed, arranged and placed to reflect and compliment the interconnectedness of attributes contained at a specific location. The footings of this approach are transferable to the design of locative experiences that deliver relationships between the physical and digital.

5. MOVING BEYOND LOCATION: SOCIAL MEDIA AND DATA AS CONTEXT IN MOBILE AUDIO SYSTEMS

Location-based audio experiences, where audio is geographically located within the world, are a common and prevalent technique to present audio in place. In its most basic form, a database of audio files is associated with a set of geographic coordinates, and presented to a user when he or she enters an activation zone (usually within a few meters) of the geographical coordinates. Whilst other location and proximity sensing technologies have been used, this basic approach has been a common technique from the earliest work (Bederson, 1995) to the amongst the latest (Ciolfi & McLoughlin, 2012). Significant technical advances have been made, moving from straightforward playback of audio (Bederson, 1995) to the use of virtual spatialized auditory environments that can present multiple overlapping sounds, and vary the sounds presented based on user distance from the geographic source (Vazquez-Alvarez, Oakley, & Brewster, 2011). However, the audio itself is often fixed (existing as a procreated file on the user's mobile device) and is manually curated and fixed to a geographical location. This manual creation means that users have a "canned" experience, where the same audio is triggered in the same physical location. This works well for many of the, usually cultural heritage, applications where location-based audio is employed to augment and enhance existing physical places. As Smith (Smith, 2011) notes: "heritage is not the historic monument, archaeological site, or museum artefact, but rather the activities that occur at them". The embodied experience (Ciolfi, 2015) of location-based audio is well placed to fulfil this role, contextualising the built environment.

For example, Reid et al. (Reid, Geelhoed, Hull, Cater, & Clayton, 2005) evaluated a location-based audio play about riots that had taken place in a city square. Audio vignettes were triggered as users strolled around the square, being played in contextually relevant places (e.g. the sound of rioters plundering buildings were played near the buildings the referred to). Such work assumes that the augmented experience is "visited", with the user interacting with the audio-augmented environment as their primary purpose, before switching it off and doing something else. There is also no assumption that the user would revisit the experience (in much the same way as he or she may only visit a museum exhibition once), given its static nature.

With increasing amounts of user-generated content being tagged with the location of its creation, and an increasing focus on community participation in the creation of cultural heritage (Han, Shih, Rosson, & Carroll, 2014), where users create geo-located content about the history of their local area, we argue it is both valuable and necessary to consider how location-based audio could act as a ubiquitous means to gain new insight into everyday environments. Through content being dynamic, there is value in more continuous use, with the auditory environment becoming secondary to the user's main activity. Allowing, for example, the user to gain understanding of the 'heritage' of place (Smith, 2011), as a by-product of another activity. For example, going for a jog could be a way to learn about what is going on in the community via the same sort of location-based audio system as studied by Reid et al. (Reid et al., 2005).

Doing so however raises new issues and challenges. We briefly present two examples of our own work that are designed to be used in this way. PULSE (McGookin & Brewster, 2012a): an auditory display to present geotagged twitter messages in situ; and Explore: a cultural heritage 'app' that incorporates seasonal (winter and summer) variations into its content. We outline how reflections of both highlight challenges dynamic audio display of content to help contextualise the environment.

5.1. Pulse

PULSE (McGookin & Brewster, 2012b) was designed to allow users to gain a 'vibe' - an intrinsic understanding of the people, places and activities around their current location - derived from the Twitter social media service (www.twitter.com). PULSE ran as an `app' on an iPhone, with a passive user interaction: interaction was driven solely by a user's physical movement through their environment. As users moved, PULSE downloaded public Twitter messages ('tweets') generated by any user in the current location. Periodically, PULSE would select the closest tweet, synthesize it using a high quality Text-to-Speech engine and insert it in a virtual 3D auditory environment. Thus users heard tweets as whispered conversations in passing. These audio tweets were augmented with meta-data (such as the rate of message generation or trends in message topic) based on the immediate geographical area. These were either presented to users implicitly (such as mapping the time between spoken message presentations to the rate tweets were being created in the area), or explicitly (by mapping these onto an ambient water soundscape. Open ear buds were used to allow merging between the virtual and real auditory environment. We evaluated PULSE over a two-week period in Edinburgh, UK. A group of five local residents were asked to use each of the two versions of PULSE as they wished over a five-day period. In-line with our earlier discussion, PULSE was used as a secondary activity, being integrated within other activities, rather than participants setting time aside to use it.

5.2. Explore

Explore (Mcgookin et al., 2017) runs as an Android `app', designed to provide both triggered and ambient audio about cultural heritage on a visit to the Finnish recreational island of Serausaari in Helsinki. Although the island is rich in cultural and natural heritage, people visit for leisure and recreation. Whilst it contains an Open-Air museum, this is only part of the island's history. Visitors do not visit solely to attend the open-air museum (which is only open a few days of the year), rather they visit to experience the place and its nature. Our goal is to help inform them of the history and expand their curiosity towards the island when visiting. Whilst our work is based on existing audio-based cultural heritage (such as (Ciolfi & McLoughlin, 2012; McGookin, Vazquez-Alvarez, Brewster, & Bergstrom-Lehtovirta, 2012)), but unlike these "dipping" in and out of content as it becomes available and as a natural experience of visiting the place. Explore presents standard notifications as a user comes near geo-located content (historical images, audio vignettes or videos). Explore also supports seasonality of content, as the temperature can vary between -20 to +20 degrees centigrade. Two sets of content, presenting a winter and summer perspective, could be switched between by participants. A field study involving forty-five visitors to the island was conducted to evaluate Explore.

5.3. Future Challenges

Based on the results of both studies we outline issues and challenges that should be further considered when applying location-based audio more widely.

5.3.1. The World Changes

In Explore participants could switch between either the current season (summer) or out of season content (winter), whilst the users of PULSE heard tweets generated over the previous 24 hours. The temporal relationship between when the content was located and when it was heard was important. Whilst participants were open to viewing visual content in Explore that reflected the content out of season, such as the current environment in the winter, audio content, such as vignettes of historical individuals jarred when heard out of season. Similarly, with PULSE, participants identified tweets they heard that didn't correlate with the current environment. For example, a tweet generated about going to the park because it was a sunny day, when the environment was sunny, jarred with a participant hearing it in the park a few hours later when it was raining. Yet other messages with a similar gap between creation and hearing did not do this. As audio is always heard as an integration into the existing environment, rather than being clearly different to it (e.g. viewing visual content on a screen), it may be participants are more sensitive to audio incongruence. How the dynamic elements of the environment (morning to evening, weather conditions etc.) affect the relevance of content, and how this should be incorporated into mobile audio work is an underdeveloped area.

5.3.2. Filtering and Prioritising Content

In Explore, participants found it annoying when a high density of notifications were presented in quick succession. This was common in areas where there was a lot of content. In the work described by Han et al. (Han et al., 2014), it is likely that some places would have high levels of content, whilst others would be lower. How to prioritise and filter this content to avoid user annoyance is important. However, our work in PULSE shows that content viewed as mundane, or low priority, can be interesting because it is presented in situ via audio. With several instances of mundane, everyday messages highlighted because of this. Whilst not overloading the user is important, audio can change the nature of what a user may consider most insightful.

5.3.3. Considering Interaction as a Secondary Task

Both PULSE and Explore were used as ancillary to the user's main activity. In Explore, the previously mentioned notification density was highlighted as an issue, whilst with PULSE the ambient audio to represent metadata about the current area was either "tuned out" by participants, or could distract them from their primary tasks (e.g. one participant noted how he left a supermarket without collecting his change). Pervasive and immersive audio experiences (e.g. (McGookin et al., 2012; Vazquez-Alvarez et al., 2011)), when interaction is a primary experience don't work. Users will only interact with short periods of time. Whilst we used notifications, these did not help immerse users in the content. Work supporting these shorter interactions in a more immersive way is important. A potential solution might be to work of (Fosh, Benford, Reeves, Koleva, & Brundell, 2013) in considering trajectories to create short immersive experiences the transition quickly into and out of the audio content, without disruption of the primary activity.

5.3.4. The Concurrency of Places

Participants in PULSE were local, using it in familiar locations. However, in many cases it supported the discovery of new places and events in familiar environments. In particular, awareness of social activities or groups of people with divergent interests to their own: "You've got the 'God I've such a hangover this morning' ones. Which are a bit boring, but also interesting in a way, cause it reminds you of a social group of people". Another noted a message from a performer in the Edinburgh festival that was taking place during our study: "This guy who said it was two and a half hours till his show started. That was quite interesting. Seeing it from the other side." In this way, PULSE was able to illustrate how different communities (or `places') could exist concurrently in the same space. User understanding of these familiar environments was changed and provoked, highlighting other communities of practice, rather than them being "perceptually hidden" due to familiarity. Our use of a passive auditory display allowed this to occur serendipitously, with participants 'stumbling' upon new insights during their regular activities, rather than having to explicitly consider looking for them.

6. EXPERIMENTING WITH THE PAST: FICTIONAL FUTURES AS MATERIAL FOR COMPOSITION AND DESIGN

We have conducted a series of experiments, under the banner of "numbers into notes", in which the mathematics of the early 19th century is used to generate music that is guided by human and machine interaction. Our approach plays at once into generative design and into alternative histories of algorithms and mechanisms. We describe a scenario in which devices placed in an interactive space blur the traditional boundaries of composer, performer and audience, and simultaneously question the creative boundaries of human and machine.

Our work is re-imagining prospective and theoretical technologies of Ada Lovelace's time today, inspiring new responses and discoveries relating to music practice and the philosophy and history of technology. By co-designing digital and digital-physical artefacts to interpret the writing and times of Lovelace and Babbage, we enable critical reflection and re-interpretation. We frame this approach as experimental humanities: through making, through prototyping and co-design, we close-read the thought processes Lovelace and Babbage recorded, and we can point to paths in the development of computing and programming that were not taken, digitally reaching beyond what was practicable in the nineteenth century.

6.1. Historical Context

Charles Babbage gave a seminar about his proposed steam-powered computer, the Analytical Engine, at the University of Turin in 1840. Originally translated into French for publication, in 1842 Ada Lovelace translated it into English and added extensive notes. Famously these notes contain the first algorithm designed for execution by a general-purpose computing machine, which is often celebrated as the first computer program. They also contain two important ideas which have been taken up in subsequent academic debate and inform our work:

- "Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent." (note A in Menabrea, 1843). This is often cited within the computers and music domain;
- "The Analytical Engine has no pretensions to originate anything. It can do whatever we know how to order it to perform. It can follow analysis; but it has no power of anticipating any analytical relations or truths. Its province is to assist us to making available what we are already acquainted with." (note G in Menabrea, 1843), Lovelace's italics), This is cited in debates around computers and creativity, in particular by Turing in the "imitation game" paper (Turing, 1950) and, in turn, Margaret Boden in her "Lovelace questions" (Boden, 1990).

6.2. Experiments

December 2015 saw the 200th anniversary of Lovelace's birth, and a major symposium was held to mark the occasion. This included the discussion of a thought experiment: had Lovelace lived longer, and had Babbage successfully built the analytical engine, what might have happened in pursuit of Lovelace's musical observation? (Howard E. and De Roure D., 2015)

As part of this experiment we hypothesized a workflow involving the analytical engine: the machine runs a parameterized program to generate a number sequence, and parts of this sequence are then given to different instruments. We demonstrated this with an emulator and then developed an interactive Web Audio tool so that, without specialist knowledge, anyone can simply map integer sequences for musical expression. The interactive tool, a single page web application, provides several algorithms which illustrate the mathematics of the early 19th century (http://demeter.oerc.ox.ac.uk/NumbersIntoNotes). Inspired by the use of punched cards in the Jacquard loom and the proposed analytical engine, we generated virtual 'piano rolls' and a MIDI output than can be imported into other tools for editing or performance.

The next part of our thought experiment was to ask "what would Lovelace do today?" The proposed analytical engine architecture was impressive even by today's standards; for example, 167 binary bits would be required today to achieve its 50 decimal digit arithmetic. However, precision aside, today the algorithms run readily (and in real time) on the processors of open source Arduino hardware, such as an 8 bit microcontroller, or 32 bit ARM.

Our first experiment was to build the Arduino analytical engine. With a slave audio processor (VS1053[1]) and 3W amplifier to drive speakers, we replicated the Numbers into Notes tool as a small standalone "music engine".

Five of these devices were constructed, with a variety of sensors to influence the parameters of the algorithms: our prototypes used infrared remote controls and ultrasound proximity measures. These can be located in an interactive space. Here we exploit a musical outcome of our earlier work: multiple sequences played alongside each other generate harmonies, and this effect is richer when sequences are played at different but geometrically related tempos (e.g. 120, 60, 30 beats per minute). The resulting harmony sequences are experienced according to the location and orientation of the listener relative to the devices.

The multiple deployed devices are effectively coupled by the humans situated in the space, and the resulting composition is emergent. We could approach that as humans entering the space and composing an "experience" for other humans who follow them, going in and interacting—creating the locative audio interactively and asynchronously. The experience is therefore socially and mathematically co-constituted. Now we can return to Lovelace note G and ask whether the computer originates the music? Furthermore, in our demonstration at Mobile HCI (De Roure &Willcox, 2016) we recognized that no space is free from signals, as we experienced the interactions of multiple audio and infrared devices in the same physical space.

What would happen with more arduinos and how might they be configured? To explore this we created a simulation using the netLogo agent-based simulation environment. The simulation enables us to explore new design features and increasing scale. For example, the simulated arduinos (turtles) can 'hear' each other and respond, there are multiple types of arduino, and they can be programmed to move.

6.2.1. Closing Thoughts –Mobile Music-Boxes

The 1800s saw mechanical music machines of various descriptions, with the devices producing the music positioned in the home or public space. In the intervening years, we have moved towards making recordings of performances and replaying these; indeed, much of today's recording industry works on this basis. However, we are now able to create digital-physical simulations of music boxes and automata, and to explore how these might have developed.

7. CONCLUSION

This paper has presented a series of perspectives that focused upon mobile HCI and audio. Each of these perspectives although different has highlighted the breadth of research in this growing area, each with their own challenges and issues. As mobile technologies and communication infrastructure, and mobile audio input/out mechanisms develop new opportunities become more apparent. As mobile HCI moves into 'new' territory it becomes apparent that what are needed are new approaches and methods that allow researchers to both understand and design interactive systems. One of the key lessons learnt from the workshop was not to underestimate the research areas and fields that are looking for ways to develop and understand new ways of using audio-based mobile technologies. With this in mind the future of mobile interaction will offer an exciting range of opportunities across many fields of research.

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