Percussionist-Centred Design for Touchscreen Digital Musical Instruments

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Abstract

This article[1] describes how percussive interaction informed the design, development and deployment of a series of touchscreen digital musical instruments for ensembles. Percussion has previously been defined by techniques for exploring and interacting with instruments, rather than by the instruments themselves. Percussionists routinely co-opt unusual objects as instruments or create them from scratch. In this article, this process is used for the iterative design and evaluation of five mobile music apps by percussion ensembles. The groups helped refine the apps from prototype to performance through research rehearsals where they improvised, explored new musical gestures, and collaborated to develop practical performance strategies. As a result, the affordances and limitations of the apps were discovered, as were a vocabulary of percussive touch gestures. This article argues that this percussionist-centred process was an effective method for developing musical apps, and that it could be applied more widely in designing musical computer systems.

Keywords: Percussion; Digital Musical Instruments (DMI); Design; Mobile Music; Collaborative Development; Human-Computer Interaction (HCI)

1 Introduction

Percussionists are well-known as the sonic explorers of the Western art music world, a reputation earned through a century of experimentation in collaboration with composers and ensembles, as well as in improvisation. Far from niche activities, the processes of co-opting household objects for concert use and developing unique modes of performance on conventional instruments are included in classical percussion education. In this article, this tradition of exploration and extension is recontextualized as a design process for developing new digital musical instruments (DMIs). To illustrate this process, five mobile music apps for iPad tablets will be introduced that were all developed in collaboration with percussionists. While still in prototype form, these apps were given to percussion ensembles who incorporated them as instruments into their practice of free improvisation. Over the course of rehearsals and concerts, the percussionists

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discovered techniques for making the best musical use of these computer instruments which could then be redesigned to better meet the performers' needs. The refined DMIs could then be distributed to non-percussionists, and even non-musicians.

Early applications of this process closely followed the artistic needs of the percussionists in preparing for public performances. Feedback from rehearsals could be used to identify techniques for performing with these apps, potential design refinements, and hidden musical affordances of their design. Later, the process was modified to compare systematically several touchscreen digital musical instrument designs without necessarily leading to a public performance. Much of the percussionists' process was retained in these research rehearsals, even when the apps were used by non-percussionists. Examination of the development of each app reveals how the particular approaches to performance development taken by the percussion ensembles resulted in improvements to the app design. These performers discovered how to use the instruments through performance itself, leading to more intuitive and useful interaction designs. They pushed the boundaries of touchscreen gesture beyond what had been imagined initially, not only discovering new sounds, but inspiring the refinement of more expressive interactions. They collaborated in rehearsal and performance, demanding not just expressive instruments, but flexible ones that could play multiple roles in ensemble interaction. The combination of exploratory gestural performance, high demands for expression and flexibility, and iterative, collaborative performance development led not just to rewarding artistic outcomes, but also to refined design and understanding of the DMIs that were produced.

Much of the research discussed in this paper occurred in Canberra, Australia, where a percussion group, Ensemble Metatone, was founded to explore the musical potential of these iPad apps. The rehearsals and performances of this group were research-led and often took place in university campuses; but the group also contributed to Canberra's experimental arts scene with concerts in galleries, vacant shops and cafés. Some apps were even site-specific to performance locations in Canberra, incorporating images and sounds from the location into the digital instrument design. The group also performed elsewhere in Australia, with concerts in Sydney, Melbourne, and Newcastle having an important contribution to the artistic outcomes of this research.

1.1 Designing new interfaces for musical expression

In this article I will describe a research-led process for designing new digital musical instruments. This activity is part of the field of New Interfaces for Musical Expression (NIME) (Poupyrev, Lyons, Fels, & Blaine (Bean), 2001), where researchers and musicians work together to create novel instruments, augment existing ones to create hyper-instruments, and push the boundaries of performance and artistic practice. Rowe (1993) suggested that such interactive music systems can be modelled in three stages: input, where the performer's actions are sensed; processing, where these actions are mapped to musical intentions; and result, where the musical commands are synthesized into sonic (or other) output. Designing such interfaces, however, presents many challenges that the NIME community have identified and countered with design recommendations and processes (Medeiros, Calegario, Cabral, & Ramalho, 2014). P. Cook (2001) suggested principles for designing computer music controllers, emphasizing the potential of simple controllers, such as sensors applied to household objects, used creatively. Hunt, Wanderley, and Paradis (2003) noted that the processing stage involves choosing from a potentially large space of mappings between input and result, so a single NIME can have many different behaviours. Maintaining a strong link between the musician's gesture and the resulting musical output that emphasizes the liveness of performance is another design challenge (Croft, 2007). While it may seem possible to control a very large number of synthesis processes with a single interface, this can lead to a feeling of disconnection and lack of embodiment in performances.

Musical interface research has also borrowed concepts from human-computer interaction (HCI), where design procedures have been codified to address the challenges of creating and using new computer systems. A critical notion for this research is that of user-centred design, articulated by Norman (1988). In user-centred design, the requirements, abilities, and limitations of users are of primary consideration in designing a computer interface. This process can also be applied to DMI design; however, the process is inverted to some extent in our research, where the user (performer), has a fundamental role in discovering the musical possibilities of the instruments and defining their requirements and abilities in artistic practice. Another widely borrowed concept from HCI and design is the notion of the affordances, or action possibilities, of an interface (Norman, 1988). It has been noted that mobile devices are ideal platforms for DMI development, because their touch-screens, GPS and acceleration sensors, and powerful processors afford many potential instrument designs (Tanaka, 2010). While Norman's affordances were perceivable, such as the notes on a virtual touchscreen keyboard, hidden affordances are also possible (Gaver, 1991). In a DMI, these might only be discovered under certain performance conditions, or revealed by the actions of an expert performer. Finally, an iterative process is often used to achieve user-centred design. In iterative design, prototypes are used, evaluated, and subsequently refined several times to improve usability (Nielsen, 1993). In a musical context, DMI design iterations can occur in between a series of rehearsals or performances.

It should be noted that percussion and percussionists have an active role in the world of NIME research. Lai (2012) explored integration of mobile DMIs into percussion improvisations, as well as percussive approaches to table-top performance (Lai, 2009). Tindale (2007) and Aimi (2007) extended electronic drum design with enhanced digital signal processing. Percussion instruments are often integrated into robotic systems, such as the robotic marimba player 'Shimon' (Hoffman & Weinberg, 2011), and even ensembles of robotic instruments (Kapur et al., 2011). Electronic actuation of vibraphones (Britt, Snyder, & McPherson, 2012) and other percussion instruments (Sheffield & Gurevich, 2015) has resulted in new possibilities. In Australia, Robbie Avenaim performs alongside robotic bass drums and other instruments in his S.A.R.P.S (Semi Automated Percussion System) project (Avenaim, 2016) while Dale Gorfinkel extends vibraphone performance, with vibrating motors and spinning wheels that activate the bars (Avenaim & Gorfinkel, 2006). The use of percussion in some of these projects can often be explained by the simplicity of percussion instruments, for example, it is far easier to build robotic percussion performers than brass players. In this article, however, I argue that percussionists bring a special style of performance to DMIs that can be considered part of the design process.

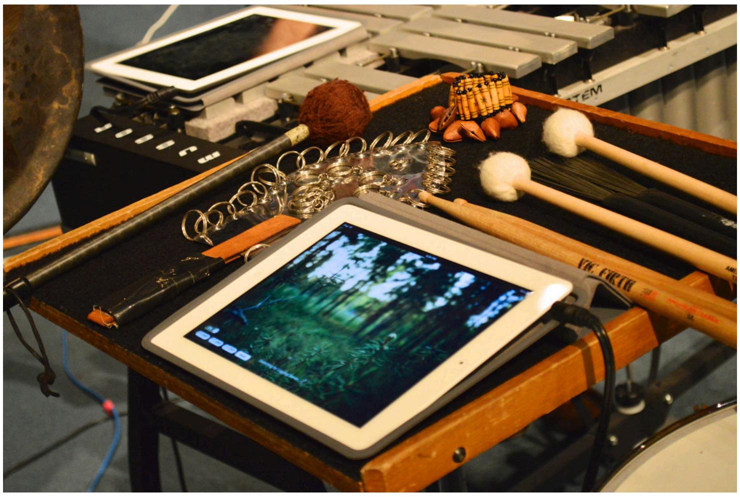

Figure 1: Tablet computers such as iPads fit well into percussion setups because of their physical size, and the percussive affordances of their touchscreens.

1.2 Percussionist-centred design

The musical practice of percussion is better defined by methods of interacting with instruments than the instruments themselves. Percussionists perform by 'striking, scraping, brushing, rubbing, whacking, or crashing any and practically every available object' (2006, p. 5). Classifications of percussion instruments often divide them by how they are used. The earliest percussion instruments were idiophones, where the body of the instrument creates the sound rather than a skin or string. Blades (1992) classified such instruments by how they are played (p. 36): 'shaken', 'stamping' (played with the hands or feet), 'scraped', 'concussion' (two parts struck together), and 'struck' (with a stick or non-sounding implement). Taxonomies of modern percussion instruments (e.g., G. Cook (1997)) also focus on how performers interact with the instruments, rather than on the instruments' physical design.

Of course, percussionists often experiment with their percussive interactions to coax new timbres out of familiar instruments. They also apply these musical gestures to traditionally non-musical objects to discover unique sounds. For example, performers of Xenakis' (1975) *Psappha* or Feldman's (1965) *King of Denmark* must create their own setup of multiple instruments to fit each composer's specifications. The performer might find a car's suspension spring or a saw-blade to meet the composer's call for a metal instrument, and explore a variety of implements and playing techniques to extract a satisfying sound. This process of gestural exploration can also be applied in free improvisation, where percussionists might aim to discover new sounds in real-time from traditional and non-traditional instruments, while responding to other sounds in an ensemble. Free improvisation has been established as a standard practice by percussion ensembles and included in music pedagogy, such as Cahn's (2005) Creative Music Making.

The use of touch-screen mobile devices, such as smartphones and tablets, to make music is now well established. Apps such as Smule's Ocarina (Wang,

2014) and Magic Fiddle (Wang, Oh, & Lieber, 2011) have demonstrated some of the creative musical possibilities that these devices hold, but many other mainstream apps, such as Apple Inc.'s (2011) Garageband, are limited to very simple creative interactions, such as tapping virtual piano keys. The touchscreens of these devices, like percussion instruments, can be struck, scraped and rubbed with fingers and hands. These affordances suggest that exploration by percussionists can establish more varied modes of interaction. A process where such exploration is used as part of the development of a DMI could be termed *percussionist-centred* design. Below, I provide an account of the way this percussionist-centred process can be used to assist with the design of DMI apps running on tablet computers. While many touch sensor based DMIs have been explored in NIME research, Apple iPads were chosen for these projects because of their widespread adoption and established development frameworks for musical applications. Even though iPad touchscreens have drawbacks, such as a lack of pressure sensitivity or physical feedback, their physical dimensions mimic that of some simple percussion instruments, such as the woodblock or tambourine. As shown in Figure 1, they fit conveniently into conventional percussion setups. One potential limitation of using iPads for percussion performance is the latency between screen touches and output sound. Ng, Lepinski, Wigdor, Sanders, and Dietz (2012) note that commercial touchscreen systems have a display latency somewhere between '50-200 ms' (p. 453) while Michon, Smith III, and Orlarey (2015) report a touch to sound latency of 45 ms on an iPad 2 and just 36 ms on a more powerful iPhone 5 (p. 397). While very low latency is desirable in an interactive music system (Wright & Brandt, 2001), Mäki-Patola and Hämäläinen (2004) found that playing style affects the detection of latency, and suggest that the type of music and nature of the sound affect latency tolerance. Despite the limitations of the iPad, the research described below shows that it can be played musically and expressively, and that touch to sound latency appears to be sufficient for ensemble improvisation.

The research discussed in this article was practice-led (Candy, 2006) and the author participated in the artistic process as an ensemble member, as well as designing the apps that were used. In creative arts research it is a well-established methodology for a practitioner/researcher to examine their own practice, particularly in 'new media and music' (Smith & Dean, 2009, p. 8). In HCI, such methodology has been described as autobiographical design, a practice that allows in depth examination of long term usage of a system at the early stages of development (Neustaedter & Sengers, 2012). It should also be noted that the apps and research processes described in this article were the topic of the author's PhD thesis (C. P. Martin, 2016).

2 Designing apps for percussionists

The apps described in this article were specifically designed for exploration by percussion ensembles in free improvisation. The early goal of these apps was to reveal new ways that mobile computer music devices could be integrated into this established chamber music configuration. While integrating computer music into percussion performance via a laptop running Max to process percussion sounds, or to create backing sound tracks, is a well understood mode of performance, these mobile apps allowed the performers to hold the computer

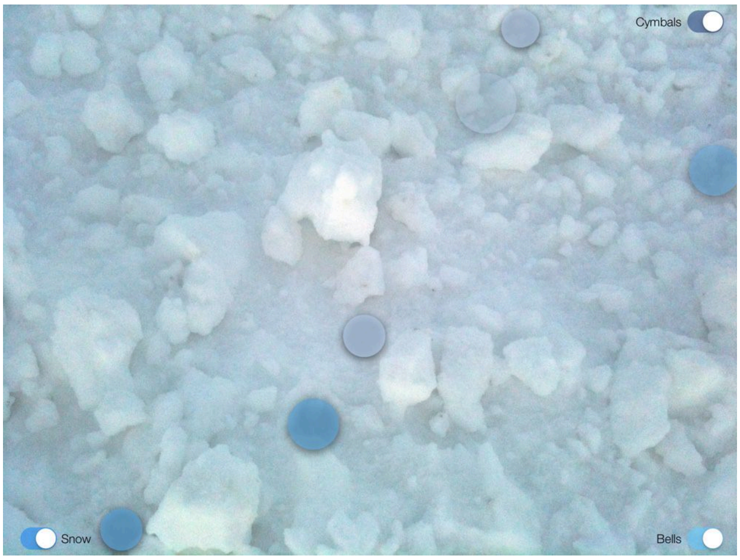

Figure 2: The interface of Snow Music, this app allows the player to manipulate samples of snow with their touch gestures. The GUI buttons controlled generative music processes. The blue circles represent notes triggered by these processes. A video demo of Snow Music is available at doi:10.5281/zenodo.51820.

sounds in their hands, so to speak, and to explore them like any other percussion instrument.

These apps were designed with an interaction scheme that was percussion-inspired, and allowed access to synthesized pitched percussion sounds and field recordings. The whole screen of the iPad was dedicated to free-form musical interaction with few graphical user interface (GUI) widgets. Tapping the screen in any location produced short sounds at a pitch determined by the location of the tap. Swiping triggered continuous sounds, with the volume directly mapped to the velocity of the swipe. The first iteration of this design can be seen in the Snow Music app, shown in Figure 2.

The simple (and even simplistic) design of these apps positioned them in opposition to the typical design of computer based DMIs used in percussion setups. Max patches often include dozens of user interface widgets, such as buttons and number fields for adjusting the parameters of the program. While these can be used to customize the program, in general, it isn't practical to edit them during performance. Digital audio workstation software such as Ableton Live is also popular for use in live performance, as are sophisticated hardware devices such as looping and effects pedals. While these systems are extremely flexible, their use involves in depth learning, experimentation and composition before performance can take place.

The fundamental idea of Snow Music, and later apps, was to investigate how computer music performance could to be developed in the moment, through free improvisation in rehearsal, or even in front of an audience. To achieve these goals, the apps did not include settings menus or detailed configurations. In order to play new sounds, performers had to discover them through performance by manipulating the touchscreen, observing others in the ensemble, and listening

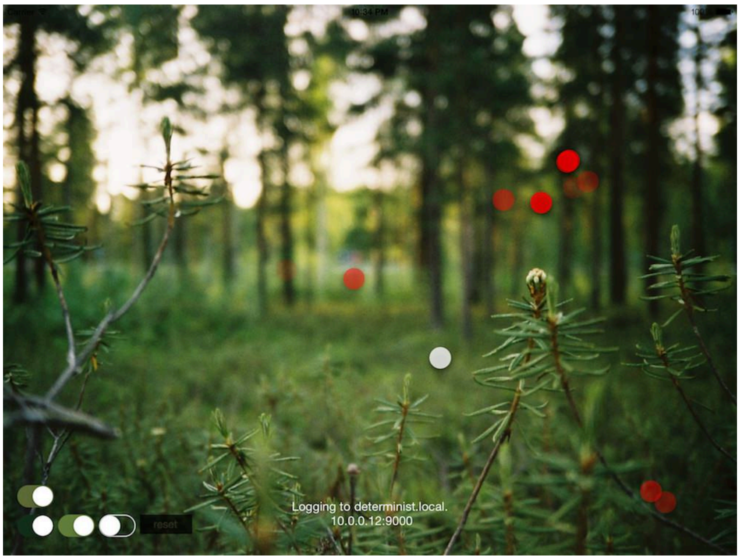

Figure 3: Screenshot of the MetaTravels app. The white circle represents the user's touch point while red circles are looped touches. Four switches at the lower left corner control algorithmic background sound generators and a looping feature, and a button shuffles the sounds available to the player from the app's palette. A video demo of MetaTravels is available at doi:10.5281/zenodo.51814.

to the results.

Most of the sounds in the apps needed to be triggered by direct and continuous interaction with the touchscreen. However, a very small number of features were added to enable sounds that continued even while the performer was not touching the screen. The idea of these features was to assist the performers' use of the apps in percussion setups while their attention was focused elsewhere. These features were activated by small GUI switches placed in the corners of the touchscreen.

The earliest apps developed in this process were standalone; that is, they operated without any connections to other devices, and as independent instruments. Later apps, however, included networking features that connected the ensemble's apps to each other and to external computers. While the full implications of performing with networked instruments is beyond the scope of this article, some consequences of using the networked DMIs will be discussed below.

2.1 Developing Snow Music and MetaTravels

The two earliest apps designed for use in this project were Snow Music and MetaTravels (shown in figures 2 and 3). These apps had very similar interfaces but different sonic material. Both were presented to a percussion ensemble in prototype form, and actively developed over a series of rehearsals and performances. In each case, the rehearsals were conducted as part of artistic research projects; the goals of these projects, however, were different. Snow Music's rehearsal and performance process was intended to establish the viability of the use of mobile computing devices in a percussion ensemble situation. One finding of this research was that the percussionists developed new ways of interacting with the touchscreens in order to support their music making. In turn, MetaTravels' research process sought to define a vocabulary of musical touch-gestures that could inform the designs of future apps and touchscreen music pedagogy.

Snow Music was designed to emulate a bowl of snow, allowing performers to manipulate recordings of snow being squished, smeared, stomped and smashed. These snow field recordings were triggered and controlled by tapping, swiping and swirling in the free-form touch area represented by the snow image that covered the majority of the iPad screen. Touch interaction with Snow Music was divided between two fundamental touch events exposed in Apple's iOS operating system (Apple, 2015). `touchDown` events are triggered every time the user touches the screen, and these events triggered a sound with a percussive envelope (i.e., a short attack, no sustain and longer release). `touchMoved` events are triggered when a user has already touched the screen and moved the touch point. These events were used to control a continuous sound with amplitude proportional to the speed of the moving touch. Apple's `UIPanGestureRecognizer` class was used to keep track of the movements of a single touch, so that one continuous sound and many taps could be performed simultaneously.

Three GUI switch widgets were also included in Snow Music's touch screen interface. Each of these switches activated a continuous musical process that was algorithmically generated: snowy winds, shimmering cymbals and icy bells. When activated, each of these processes would play short sequences of notes with randomly chosen pitch and rhythm, in between pauses of variable length. The rhythm for these notes was intended to be free and did not adhere to a particular metre; the pitches for the bells were taken from the C minor scale; and the other sounds were pitch shifted a random amount from their original recordings. This process would continue until the GUI switches were deactivated.

Snow Music was designed for use by Ensemble Evolution, a percussion ensemble who had already established a performance practice including free improvisation. The mobile DMI was used alongside the other percussion instruments in the performers' setups (see Figure 4a). Over several improvisations, the performers were able to give feedback on the app design, which was updated in between each rehearsal. At the end of this process, the group had established an improvisation style with the app, which was then used in a series of live performances (C. Martin, 2012).

In contrast, MetaTravels was intended to be the main instrument for a newly established percussion group, Ensemble Metatone (see Figure 4b). The app needed to afford sufficiently expressive sonic possibilities and support long improvisations without relying on other instruments or software. Where Snow Music was limited to direct performance with snow samples, MetaTravels allowed the performers to play with a range of sound material, including pitched and unpitched percussion sounds, and field recordings made around the world. MetaTravels used a radial scheme for assigning pitch to locations on the touchscreen, although this was not visually indicated in the GUI. Taps in the centre of the screen were assigned the lowest pitch (MIDI note 30), with pitches increasing linearly as the distance from the centre increased, with the highest notes located in the corners of the iPad screen (MIDI note 94). Pitches of notes were quantized to integer MIDI values, corresponding to equal temperament, chromatic pitches.

MetaTravels was loaded with field recordings made in Sweden and Japan, as well as samples of almglocken (tuned cowbells), a singing bowl and three different suspended cymbals. Taps on the screen played either field recordings, instrument samples, or both at the same time. Moving touches always played field recordings. The particular samples that were played by taps and moving touches in the app could not be directly specified by the user; but a GUI 'reset' button was present on the screen which would shuffle between the samples. The rationale for the reset button and the unmarked pitch interface was to eliminate menus and configuration screens from the app in favour of an exploratory model of performance. Rather than selecting sounds and pitches before playing them, the user would have to experiment by playing the app and shuffling the sounds only if they were not satisfied with the current selections. This model emphasized listening and interaction with the interface rather than operating a menu-heavy user interface.

Four GUI switches were included in MetaTravels' on-screen interface. Three of these switches toggled algorithmic sound generators similar to those in Snow Music. The final GUI switch controlled a looping function. This feature repeated each note tapped by the performers, after a delay of five seconds, between five and fifteen times. After each repeat the looping time was lengthened slightly, and the position of the tapped note moved slightly towards the centre of the screen. The musical result of this modulation was that a short melody would undergo noticeable sonic changes as it was repeated. The first few repeats would be recognisable, but after a few repeats, the notes would play at a much lower pitch (as the touch points moved towards the centre of the screen) and the rhythm would become quite different. This process would continue until the looped notes exhausted their assigned number of loops. In this way, the looping feature worked differently to typical digital delay effects, which repeat sounds in the same rhythm at each delay with a volume that reduces after each repeat at a constant rate.

Like Snow Music, MetaTravels was introduced to a percussion ensemble at an early stage of its development. The ensemble explored the app in a structured process of Creative Music Making (Cahn, 2005) over several rehearsals. Following the principles of iterative design, feedback from the performers was incorporated in revisions in between ensemble sessions. Recordings of the sessions were also analyzed through a qualitative research process resulting in a vocabulary of performative percussive interactions with touchscreens (C. Martin, Gardner, & Swift, 2014).

Playing to the exploratory performance skills of the percussionists, both Snow Music and MetaTravels emphasized discovery within performance. Some of the most exciting moments of the sessions happened when the performers discovered hidden affordances of the apps that were not intentionally included in the design. For instance, while the looping function of MetaTravels was intended to build up layers of melodies, the percussionists used it while playing very fast taps in the same screen location. Depending on the sample that was active, this continuous sound could recall a buzz roll or an organ-like drone. Far from mistakes, this and other discovered sounds became key aspects of the group's playing in subsequent sessions and live performances.

(a) Ensemble Evolution performing with the Snow Music app along with other percussion instruments and a guest artist on laptop. This performance took place at the Victorian College of Arts, Melbourne, March 2012.

(b) Ensemble Metatone in an iPad-only rehearsal (April 2013) at the Australian National University's School of Music. All performers were using the MetaTravels app. Videos and data from this performance are available at doi:10.5281/zenodo.51595.

Figure 4: Snow Music was an app designed to be used with the other percussion instruments used by an ensemble while MetaTravels could be used as the main instrument for a group. Both apps were explored over multiple free-improvised rehearsals and performances.

Figure 5: Screenshot of the MetaLonsdale app. The app is broadly similar to MetaTravels but contains audio material focussed on cafés of Lonsdale St Traders. The reset button (labelled 'sounds') is in the lower right of the interface along with a text label showing the active scale for pitched sounds. A demo of this app is available at doi:10.5281/zenodo.51818.

2.2 MetaLonsdale and BirdsNest: Networked app designs

Having established successful modes of performance using Snow Music and MetaTravels with different percussion ensembles, two further apps were designed that iterated on the design of MetaTravels while including sonic material for specific performances. MetaLonsdale (shown in Figure 5) was developed for a site-specific performance at Everything Nothing Projects, a pop-up gallery in Canberra, and the app included field recordings and images from that location. BirdsNest (shown in Figure 6) was designed to be used in an improvised work of the same name by Ensemble Evolution. Inspired by forest sounds of Northern Sweden, this app used samples of bird calls and percussive samples from the group to complement an assortment of found sounds used by the percussionists in concert.

The touchscreen interface for MetaLonsdale and BirdsNest was very similar to that of MetaTravels. A similar free-form touch area was used, with radial assignment of pitched sounds. A palette of sonic material was also included with each app that could be shuffled using a GUI button labelled 'sounds'. Both apps included the looping function. While MetaTravels had three selectable algorithmic sound generators, the new apps had only one, labelled 'autoplay'. This simplified user interface design was chosen in response to the results of the rehearsal series with MetaTravels, where the meaning of the multiple switches was unclear to the performers, and seemed to hold less creative potential than percussive exploration of the touchscreen, sound palette and looping system.

An important new feature of MetaLonsdale was the limitation of pitches to diatonic scales rather than the chromatic scale available in MetaTravels. An Objective-C model of common musical scales was created that would allow screen positions to be easily mapped to pitches from a required scale. A sequence of scales and root keys was chosen for MetaLonsdale: F mixolydian, F# lydian and C lydian #5. Performers could progress through this sequence by tapping the reset button. This allowed performances to have a sense of harmonic progression as the scale changed during improvisation. Rather than advance one scale with each tap, MetaLonsdale only changed scale in response to 25 percent of button presses. The app did, however, shuffle the sound material with every reset tap, as with MetaTravels. A text label in the app showed the scale that was currently activated. When the app advanced to a new scale, the image backdrop was changed.

While the sequence of scales in MetaLonsdale added harmonic structure to performances, the apps could easily play clashing scales as multiple performers continually shuffled through sound material. This problem was solved with the addition of network connections between the apps that allowed scale changes in MetaLonsdale to be synchronized between users. This network functionality was designed so that when any member of the ensemble triggered a scale change on their iPad, the scale on the rest of the ensemble's iPads would change as well.

To accomplish this synchronization feature, the apps automatically advertised themselves over a WiFi network and connected to the other iPads present in the ensemble. In this way, the apps formed a network of connections and were able to synchronize aspects of their interface during the performance. Whenever an app updated its scale, it sent a message to each of the other apps in the ensemble, which updated their interfaces as well. This system was also used to mirror other interface changes across the ensemble. Each tap of the reset button and each change in switch state were communicated to the whole ensemble of iPads. While scale messages were always applied, the other apps randomly chose to react to messages for looping, autoplay and shuffling the sounds 20 percent of the time. This partial synchronization of features was designed to assign and reassign ensemble members into musical sections, as the performers found their instruments matching up in functionality and sounds throughout each performance.

In designing BirdsNest this network synchronization system was also adopted; however, BirdsNest extended its use to apply not just to scales, but to palettes of sounds as well. BirdsNest was adapted from MetaLonsdale for Ensemble Evolution's performances of a series of compositions called *Sounds of the Treetops*. The sonic material in BirdsNest was composed to reflect this theme, allowing each performer to create a journey through fields, a forest, up into the trees, and finally to a bird's-eye vantage point of the whole landscape below. This journey is communicated through a series of background images and collections of bird sounds and field recordings, as well as sampled percussion instruments, such as wood block and xylophone, which complement this musical idea. Unlike MetaLonsdale, which had a focus on a sequence of scales, BirdsNest is based around this evocative series of sound colours. Each scene has a palette of sound material, of which only a few sounds are available to each player. The sounds are triggered by tapping and swirling on the backdrop image. BirdsNest also included a GUI button that performers used to shuffle sounds, looping and autoplay functions.

BirdsNest and MetaLonsdale were successful iterations on the design that was prototyped in Snow Music and MetaTravels. The earlier apps were mainly used in a series of studio rehearsals, where the percussionists' actions on the

Figure 6: Screenshot of the BirdsNest app that features field-recordings and images from a forest in Northern Sweden. Performers create a sonic journey through this forest by exploring the available sound material from the forest floor to a bird's-eye vantage point. A video demo of BirdsNest is available at doi:10.5281/zenodo.51819.

apps were scrutinized for the benefit of the research process. Refinements developed in this process – in particular, the addition of sequences of scales and sound colours, the simplified interface, and network synchronisations – allowed BirdsNest and MetaLonsdale to be developed specifically for live performances. As with the previous apps, delivering them into the exploratory hands of percussionists revealed ways in which the new functionality enhanced and complicated performance. While the networked synchronization of scales and features added a clarified structure to performances, these features also challenged the performers using them. In essence, these instruments changed under the percussionists' fingertips due to the actions of others in the group. Such changes presented challenges to the performers: new sounds or scales could be an opportunity for a new direction in the improvisation, but could also feel like a disruption that breaks a performer's creative flow.

2.3 PhaseRings: A refined percussive touchscreen app

After successful performance experiences with BirdsNest and MetaLonsdale, a new series of apps were created in response to the limitations of these previous designs. PhaseRings featured a similar method of interaction, tapping to create short sounds and swiping or swirling to create long sounds, but with a more focused visual and sonic design. While the earlier apps featured evocative and thematic background images and palettes of a range of sounds, the visual design of PhaseRings was abstract and muted, and offered only a single sound at a time.

PhaseRings (shown in Figure 7) is an annular interface for interacting with synthesized sound. Each ring in the app represents a different pitch that the performer can activate. While the timbre and pitch material was limited com-

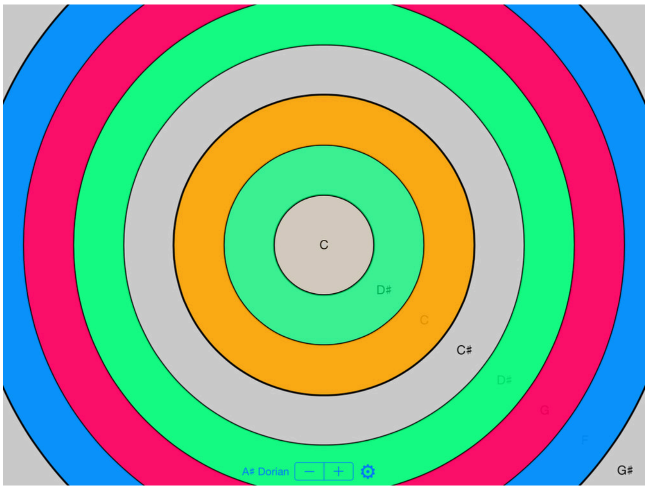

Figure 7: PhaseRings featured an annular interface with rings representing pitches that can be tapped, swirled, or swiped. A stepper control allows the user to access different setups, and a gear icon allows access to a configuration menu. The current scale is displayed in a text label. A video demo of PhaseRings is available at doi:10.5281/zenodo.51822.

pared with previous apps, PhaseRings allowed more expressive interaction with the sounds that were available by mapping different styles of touch interaction to modulations in the sound synthesis and application of audio effects. Similarly to previous apps, PhaseRings is based around a series of harmonically related musical scales. At any one time, a selection of three to ten pitches is available on the screen, with each pitch represented by a ring and a text label. This pitch 'setup', or collection of pitches available on screen, is generated from the currently active scale. In an ensemble situation, network syncing ensures that the performers have the same active scale, and thus the same harmonic location; but their pitch setups are generated independently so that they each have a unique melodic space to explore.

Some features of the PhaseRings app relied on new capabilities of Apple's iOS operating system that had recently become available. Apps were allowed to respond to touch radius in addition to location and velocity of touches. This parameter roughly captures the size of the user's touch, and can be controlled by pressing a finger more or less firmly into the screen, or using the flat or tip of a finger or thumb. Following other apps such as Orphion (Trump & Bullock, 2014), touch radius was mapped to the volume of tapped sounds in PhaseRings, and the timbre of some synthesized sounds. PhaseRings also included expanded visual feedback. When tapped or swirled, each pitch ring pulses a particular colour following a system inspired by de Maistre's (1917–1919) artworks. These works used particular colours to represent the notes of the musical octave following a system set out on 'discs, scales, and a "Colour Key Board"' (McNamara, 2009). When swirling in PhaseRings, the intensity of these colours and speed of pulsing was connected to the performer's touch velocity and position.

As with previous apps, the original design for PhaseRings, a prototype app called Singing Bowls, was presented to a percussion ensemble for initial evaluation and exploration. This prototype had a minimal interface, with no controls for changing sounds or scale and no looping or autoplay functions. Instead of allowing performers to choose when to change notes, Singing Bowls was connected over a network to an ensemble director agent, software that would choose appropriate times to update the ensemble's interfaces based on their touch gestures.[2] The earliest exploration of this concept and the Singing Bowls apps occurred in performance with a percussion septet that also included quartet performances with MetaLonsdale and BirdsNest.

At this point, Ensemble Metatone now had a repertoire of touch-screen apps in active use for improvised performance: Singing Bowls, MetaLonsdale, BirdsNest, MetaTravels and Snow Music. While some of these apps had been investigated in research-led rehearsal series, they had not been compared in a formal way. To continue to refine these apps, a formal study was devised where three percussionists from Ensemble Metatone compared improvisations with Singing Bowls, Snow Music and BirdsNest under controlled studio conditions. Rather than allow the performers to improvise freely for as long as they wanted, this study limited improvisation to five minutes, allowing eighteen performances to be recorded in one rehearsal session: three repetitions of performances with each app under two different networked agent conditions (C. Martin, Gardner, Swift, & Martin, 2015). In this study, the percussionists demonstrated a range of performance techniques to come to terms with the three different apps; but Singing Bowls, which showed the most promise for further refinement, was the focus of future work after it was renamed PhaseRings.

In some ways, PhaseRings represents the end of a purely percussionist-centred design process as it was subsequently released for use by other kinds of musicians and the general public. While apps such as BirdsNest had epitomized the concept of in-performance exploration, PhaseRings ultimately included a settings menu (activated by the gear icon in Figure 7) which allowed straightforward configuration of the sound available in the app and the sequence of scales that were the basis of the pitched rings. Further investigations of PhaseRings have focused on its networked interaction with an ensemble director agent, and ensembles of improvising performers who are not necessarily percussionists. The fundamental musical interactions of PhaseRings remain percussionist-centred: sound production is modeled on natural percussive gestures – striking and scraping – and the digital instrument remains self-contained and complementary to other instruments in setups. Further, the percussionist-centred process that led to PhaseRings favoured a focused and expressive instrument; the removal rather than addition of features; and evaluated the instrument based on its practical affordances in performance. The ease with which new users can now pick up PhaseRings and readily participate in improvised performance sessions is largely due to this design process.

3 A design methodology

The process of designing Snow Music, MetaTravels, MetaLonsdale, BirdsNest, and PhaseRings involved percussionists at every stage. We can rightly ask what these musicians contributed to this process? How did they challenge the DMI

[2]The design and motivations for the ensemble director agent are outside the scope of this article but can be found elsewhere (C. Martin, Gardner, & Swift, 2015).

designs and uncover potential refinements? In this section, three key aspects of the percussionists' approach to developing performances with computer instruments will be highlighted as principles for NIME design: that the percussionists learned to use the instruments in a real performance environment; that they used exploratory improvisation to uncover hidden affordances in the apps; and that their collaborative development of performances accelerated the process of iterative design.

3.1 Learning through performance

The percussionists who initially used Snow Music and MetaTravels did not follow an instruction manual to become proficient in touch-screen performance, but they didn't find these apps entirely intuitive to use either. It was the process of performance that informed the percussionists how best to perform. For the development of Snow Music, in particular, this process was crucial in demonstrating that the iPads could actually be used practically in concert. Early rehearsals with Snow Music concerned whether to compose for the app or improvise, and what kind of percussion setup should be used alongside the iPads. These questions were addressed by performing a series of improvisations in the rehearsal studio, and subsequent concert improvisations (C. Martin, 2012). The concept of learning to perform with the apps through performance was encoded into later app designs. MetaTravels introduced sound palettes that could only be explored performatively, by shuffling the available sounds and testing them, and not by selecting them from a menu. The design of BirdsNest further developed this concept, with a series of sound palettes corresponding to different visual scenes in the app.

The rehearsals and performances with percussionists using the apps have shown that the best way to understand a DMI is to perform with it. Improvised rehearsals and performances demanded that the apps support music making over a whole piece, and not just a technical demonstration. While the earliest versions of Snow Music could only really be used in setups with other percussion instruments, lessons learned in these performances were incorporated into MetaTravels, and later designs, where the iPad became the ensemble's main instrument. Ultimately, complete concerts could be performed from the iPads using a repertoire of different apps.

3.2 Exploratory improvisation

The percussionists in this project were gestural explorers of new DMIs. Presented with simple prototype interfaces with little visual feedback, they nevertheless found ways to create unique and varied music. The research rehearsal process with MetaTravels demonstrates the value of this process. While the app was only designed around two gestures, tapping and swiping, the percussionists discovered and articulated a vocabulary of several different types of swirls, swipes, taps and two-handed combinations of gestures during the rehearsals (C. Martin et al., 2014). They described how they used these gestures to create particular sounds that could be used to signal new sections in the improvisation, or support the other performers. Importantly, these new gestures led to sounds that were not directly designed into the app, such as drones that were created by combining fast taps, low pitched sounds and the looping function in MetaLonsdale. Having defined this gestural vocabulary, it was included in later app designs. PhaseRings included much more expressive touchscreen interactions that responded with more variation to the different gestures. BirdsNest and Snow Music were redesigned to include interaction with a gesture-tracking ensemble director agent that could detect different patterns of touches and activate specific responses (C. Martin, Gardner, & Swift, 2015).

The ability to discover hidden affordances in a DMI through exploratory improvisation is a valuable contribution to the design process. This skill requires not just creative approaches to performance, but patient investigation. Percussionists are often experts in this area not just because of their general musicality, but because finding interesting sounds and creating exciting instruments are part of percussionists' musical identity. Incorporating exploratory improvisation into the design process of the apps paid off in the later app designs; PhaseRings' annular design incorporated visual suggestion of swirling gestures and rewarded gestural investigation with effects and modulations in the output sound. As a result, PhaseRings was much more approachable to non-percussionists and non-musicians who were involved in later studies and performance workshops.

3.3 Collaborative development

Each of the apps discussed above was intended for use not by individuals, but by an ensemble of DMI performers. For percussionists, ensemble performance is much more common than solo playing, a fact that had two consequences in the app design process. First, the percussionists were comfortable exploring a collaborative DMI together, rather than learning to perform with the apps on their own and only playing together once they had reached a level of relative mastery. Secondly, because the learning process was collaborative from the outset, any discoveries that were made were shared immediately, and dead ends were abandoned readily.

The fact that these apps were prototyped in a collaborative environment put extra pressure on their design. It wasn't enough for the apps to sound interesting, they needed to blend well and support each others' sounds, while simultaneously possessing the ability to create a solo expression or direct the movement into a new musical section. These contrasting requirements and other possibilities of musical interaction were examined by the percussionists in depth during their comparative study of Snow Music, BirdsNest and Singing Bowls, where the collaborative possibilities of each app were put to the test (C. Martin, Gardner, Swift, & Martin, 2015). Other interface designers have remarked that artistic performance is a particularly rigorous benchmark for a human-computer interface (Buxton, 1997). Performance demands that interfaces support unbroken creative flow while also meeting demands for expressions that can border on extreme. Collaborative performance, then, could be an even more challenging benchmark, as these requirements need to be fulfilled for multiple performers simultaneously. On the other hand, collaborative performance could lead to a much faster process of discovery with an interface, and a tighter design loop in which to refine a design.

The experiences of designing apps with a collaborative percussion group lead to the recommendation that DMIs should be developed collaboratively. The process of ensemble performance puts extra pressure on the interface, revealing flaws and expressive limitations more readily. Simultaneous investigation of a DMI also accelerates artistic development through the sharing of discoveries and encouragement to continue exploring.

4 Conclusions

Percussionist-centred design is the process of developing new instruments while observing them in the hands of percussionists. These instrumentalists are unique in the classical world because their performance practice is defined by gestural language and not by a particular instrument. Percussionists are equipped with exploratory skills and trained to draw the most interesting and appropriate sounds out of unfamiliar instruments, particularly when performing free improvisations. In a DMI design process, percussionists have the skills to explore new interfaces themselves and not wait for an instruction manual. They discover the instrument through performance and rehearsal, share their discoveries through collaboration and evaluate the instruments through exploratory performances. In the case of the touchscreen instruments presented in this article, percussionist-centred design led to successful refinements and an instrument that was ready for distribution to new performers and improvisers. The artistic results that were achieved throughout this process were also valuable contributions to the field of new musical interface design and valuable to the musicians who were involved.

The natural design process for percussionists described here matches up with design concepts present in the fields of NIME and HCI such as iterative and user-centred design. The result in this case, however, was instruments that are appropriate to a wider audience than the percussionists that were part of the design process. After all, percussion is a democratic instrument; some percussion instruments that appear on the concert hall stage can also be seen in a pre-school classroom. It makes sense, then, that the refinements sought by percussionists in a digital instrument could be expected to apply more generally to other users. This leads then to the final recommendations of this article: DMI designers should use percussionist-centred design to refine and evaluate their systems through improvisation, exploration and live performance, even when these systems are intended for a general audience. Percussionists, too, should collaborate with DMI designers to create unique and cutting edge instruments to incorporate into their ever-evolving artistic practices.

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6 Biography

Charles Martin is a specialist in percussion, computer music and human computer interaction. He links percussion with electroacoustic music and other media through new and emerging technologies. Charles has founded ensembles specializing in interactive theatre and improvised touchscreen performance who have toured throughout Australia, Europe and the USA. In 2016, Charles joined the EPEC (Engineering Predictability with Embodied Cognition) project at the University of Oslo to develop new musical systems that predict their users' actions and preferences.

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