# NIME or Mime: A Sound-First Approach to Developing an Audio-Visual Gestural Instrument

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## ABSTRACT

This paper outlines the development process of an audio-visual gestural instrument—the *AirSticks*—and elaborates on the role 'miming' has played in the formation of new mappings for the instrument. The *AirSticks*, although fully-functioning, were used as props in live performances in order to evaluate potential mapping strategies that were later implemented for real. This use of mime when designing Digital Musical Instruments (DMIs) can help overcome choice paralysis, break from established habits, and liberate creators to realise more meaningful parameter mappings. Bringing this process into an interactive performance environment acknowledges the audience as stakeholders in the design of these instruments, and also leads us to reflect upon the beliefs and assumptions made by an audience when engaging with the performance of such 'magical' devices. This paper establishes two opposing strategies to parameter mapping, 'movement-first' mapping, and the less conventional 'sound-first' mapping that incorporates mime. We discuss the performance 'One Five Nine', its transformation from a partial mime into a fully interactive presentation, and the influence this process has had on the outcome of the performance and the *AirSticks* as a whole.

## Author Keywords

DMI, audio-visual, audio-visual performance, instrument design, design methods

## CCS Concepts

•**Applied computing** → **Sound and music computing;** *Performing arts;* •**Human-centered computing** → *HCI design and evaluation methods;*

## 1. INTRODUCTION

This paper outlines the creative process behind a solo audio-visual gestural piece, 'One Five Nine'. We compare two contrasting approaches we took during development. One approach provides the performer with nuanced control over live sound and visuals in real-time, while the other approach, that of miming over a backing-track, provides the performer freedom to explore different movements to predetermined sound and visuals.



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We suggest that miming over pre-recorded music and video with a gestural controller as a prop can help Digital Musical Instrument (DMI) designers break old habits and imagine new mappings. This is an approach we call sound-first mapping, where the actual mapping of the movement to sound and visuals is deferred until after the stakeholders—the performer and the audience—are satisfied with the outcome.

Though similar techniques have been used to improve our understanding of the connection between gestures and sound in general [3, 17, 29], our practice-based approach is composition-specific, echoing the suggestion of Perry Cook to 'make a piece, not an instrument or controller' [7]. We extend on his suggestion by also factoring in how the piece is performed physically, focusing on how it looks as much as how it sounds.

In this paper we describe the resulting mapping that was eventually constructed and gave back full real-time control over audio and visual elements to the performer. We also describe how the use of mime helped us play with the audience's perception of what is 'real' and what is 'fake' when it comes to the use of technology within a live electronic music performance. This became a core theme within the performance, inviting the audience to imagine future possibilities of human-technology interaction and question their belief system as to what was happening right in front of them.

## 2. THE AIRSTICKS

Many drummers desire a way to integrate electronic sound into live, improvised drumming performances to expand their sonic palette [6, 21, 28, 1]. Conversely, many electronic producers desire a way to present beat-oriented electronic music in a truly live context, to physicalise this music and improvise around structures produced in the studio [15, 20].

The *AirSticks* were designed to pursue both these desires. For the past seven years, the *AirSticks* have been used in many diverse musical situations—tallying well over one-hundred performances since their creation. These settings range from stage performances to films to studio recordings, and occur in solo form, but mostly in groups. A broad array of musicians, choreographers and visual artists collaborate on *AirSticks*-based projects [21].

The *AirSticks* utilise the *Razer Hydra* gaming controllers[1], which output their position and orientation into a custom software interface (CAMS) in order to control music and visuals.

The setup for 'One Five Nine' makes use of a specific pipeline of software and hardware that altogether can be considered the most up-to-date iteration of the *AirSticks* (see figure 1). CAMS sends MIDI and OSC over a net-

[1] https://support.razer.com/console/razer-hydra/

work to *Ableton Live*[2] and a real-time visualisation system built in Unity[3]. The visuals are projected onto a scrim—a transparent screen placed in front of the performer—and are aligned to the performer's position and scale to create the illusion that the virtual environment and the performer's environment are one and the same. The audience is invited into the imaginary world of the instrument, and the performer can see and interact directly with the projections situated between them and the audience.

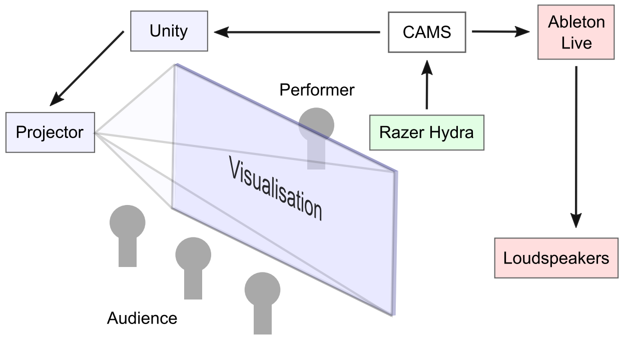


**Figure 1: The AirSticks system design.**

Over the years the *AirSticks* has been constantly redefined, and although it is a fully-functioning instrument, the act of regularly redesigning and upgrading means the *AirSticks* have never truly left the prototyping stage. The designers have made efforts to 'freeze' some states of the instrument in order to truly master it [24], but like most DMIs in the wild, the *AirSticks* are constantly evolving and adapting to knowledge learned through practice, research and reflection [30].

## 3. MAPPING APPROACHES

Gestural controllers like the *Razer Hydra* are a mixed blessing. Conveniently (and though, agonisingly) when mapping movement to sound, the possibilities are virtually limitless. It is up to DMI designers to define how their device's output data corresponds with the sound produced, but the lack of constraint can often lead to a state of 'choice paralysis' [24]. This 'mapping problem' [23] is a frequently discussed topic in the NIME community, and many authors stress the importance of gesture-sound causality in DMI design [19] for tackling this issue. An audience is likely to become alienated when a DMI lacks the instrumental gestures [4] traditionally known to accompany performance [5], and DMIs which feature a clear relationship between movement and sound have been shown to be more satisfying for audiences [11, 26, 12]. By integrating our visualisation system into *AirSticks* performance, the mapping problem is extended to a third domain beyond motion and sound—the image domain. Sonic visualisation is also a vast topic of research, plagued by the same tricky issues of parameter mapping [8, 27]. Through our creative practice we have discovered what we believe to be some effective approaches to tackle this problem and make meaningful mappings.

Two of these approaches, which are opposing but complementary, are what we refer to as *movement-first mapping* and the less conventional *sound-first mapping* (figure 2). These different approaches invite us to investigate the concepts of mapping that emerge when movement or sound are prioritised ahead of the other.

[2] https://www.ableton.com
[3] https://unity.com

When leading with movement, what considerations need to be taken? What are good metaphors to use? Striking, pulling, pushing, bending, stretching? What sounds should be made from these movements, and how should these sounds be manipulated through other gestures? These notions of movement-first mapping and mapping by gestural metaphor are often explored in the NIME community [10, 13, 25].

When leading with sound, what considerations need to be taken? What do we learn from watching musicians miming on their instruments, or kids playing air guitar? What advancements in software design would we need to better facilitate sound-first mapping? Is using a whole composition the best place to start, or a part of a piece, or a phrase, or a sample? Can using this approach help facilitate more satisfying collaborations between artists across different artforms without technology hindering the creative process? These notions are less often a point of discussion in the NIME community, though as technology continues to be developed, there several DMIs designers making breakthroughs in this area. [14, 16, 3, 17, 29].

In the development of our piece 'One Five Nine,' we utilised both approaches to continually maintain a balance between the importance of sound and movement. We will now describe how we have used these two mapping approaches in our work.

### 3.1 Movement-first mapping

This video showcases the final output of the process we identify as movement-first mapping. We recommend watching at least part of each of the videos presented throughout this paper in the order they are presented.

'One Five Nine—Introduction':
`https://youtu.be/EarmnjVqTD8`

This video is a performance of the introduction to 'One Five Nine,' centred around a five-note melody that becomes the main theme of the whole piece. It displays the expressive capabilities of the *AirSticks*. Timing can be precise, and fine control is given over velocity and timbre. The mapping used is based on the metaphor of an acoustic instrument—an approach used commonly among DMI designers [12, 26]. It is inspired by tuned percussion, and taps into common musical instrument vernacular [13].

This strategy of imagining and basing the gestures on motions from an acoustic instrument is an example of the *movement-first* approach. An action is decided upon (a strike to a tuned percussion instrument in this case) and then a sound is imagined and engineered to correspond with this movement. The sound choice initially resembles the real-world sound one would expect from the gesture, but the *AirSticks* extend this metaphor. Sound now feeds back into the process to influence the gesture, and actions of stretching and rotating are used to alter timbre after the note's initial attack. Mapping sound to these extended gestures was decided on the basis of real-world metaphors—turning an imaginary knob by rotating the wrist is assigned to a filter's cutoff and pointing left or right is assigned to panning. Sustain is controlled by maintaining the hand position below where the sound is initially triggered and release time is tied to how fast the hand is pulled back from this area.

'Electronic music often lacks a point of comparison with the natural world of sounds, providing a largely mental and imaginative experience' [18], but using the real-world metaphor of tuned percussion through a movement-first approach invites the audience to more easily understand the mechanics of the performance. This approach can also help

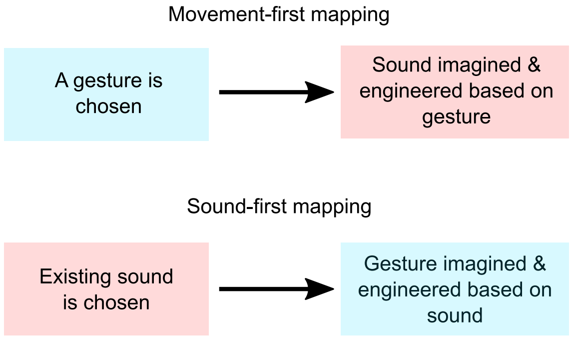


**Figure 2: Our instrument mapping approaches.**

the performer call upon the expertise they may possess on a traditional instrument with relative ease [10].

### 3.2 Sound-first mapping

The following video showcases an approach to mapping that we identify as sound-first:

'Da Funk' by *Daft Punk*:
`https://youtu.be/8fAmdGLrgvA`

In this video the *Razer Hydra* controllers are not plugged into the hub, nor is the hub plugged into a computer. This performance is completely mimed. Since the beginning of the *AirSticks* project, even before appropriate motion capture technology was discovered, the designers imagined ways of playing music through hand movements in space. Once the *AirSticks* became a reality, the technology seemed to narrow down much of the mapping possibilities. Though a language of initially engineered gestures brought the instrument to life, this language also began to limit the imaginative ways to map the instrument. Miming over a completed piece while holding the *AirSticks* could perhaps break some of these habits—it could encourage a reimagining of the way the *AirSticks* could be mapped.

The process of making this video began with listening to the piece and air-drumming along to it, noting which gestures made the most sense in representing the sound. This helped to quickly identify ways of 'playing' the music through intense listening and the imagining of the virtual playing space. As this piece of music has never existed as a physical performance, there was no *correct* way it should be mimed.

To help create the performance, movements were grouped into four categories:

1. triggering a sound
2. manipulating the sound
3. looping a phrase
4. bringing loops in and out

These sounds were then 'mapped' out—placed in the playing space starting with snare on the left, and hi-hat and kick on the right. A gesture of striking a space above the head is used to communicate that a phrase is being looped. To stop a loop, the hand is flicked upwards in the same area. A loop can be put through a high-pass filter by gesturing the turning of a knob counter-clockwise. The main melody of the song is played with the pitch mapped from left to right like a vibraphone. Special attention was given to note length and a low-pass filter on the end of the sound being controlled by the rotation of the wrist. Further parts and effects were added on top of the piece so that other gestures could be mimed along to them. All effects were pre-edited in the original music to give the illusion that they were being controlled live.

This exercise freed the established mapping processes of the *AirSticks*, and helped invent new ways to more instinctively control the sound. After we were satisfied with how the performance looked, the video became a reference for further engineering new mappings for the instrument, resulting in a mapping approach in which the imagining of sound takes the lead.

## 4. BELIEF

Though completely mimed, this performance looks like an instrument is being played. Every person with some knowledge of the *AirSticks* was convinced that it was a 'real' performance—a live remix. In music videos, lyrics are lip-synched, and all the instruments are mimed—often quite badly. This miming may be more difficult to pull off on acoustic drums, where the strike needs to be more precisely timed, but on the *AirSticks* it is easy to 'sell' that these samples are in fact being played since no surface is being struck. The audience just need to believe that this technology exists—or at least could exist.

Belief is at the heart of the audience's experience of performances featuring DMIs. The DMI designer can choose to play with the audience's idea of what is 'real'. With acoustic instruments, everything has a 'realness' to it as the connection between movement and sound is based in the physical world [26], but with DMIs this connection is broken, and can be reinvented by the designer [2]. There is no telling whether an audience member will assume a performance is 'real' regardless of whether it is mimed or not. Comments solicited from audience members after *AirSticks* performances have ranged from suggestions that interactive performances were mimed, and mimed performances were interactive. Others, such as the Sydney Morning Herald's John Shand, seemed not to concern themselves with the performer's level of control, instead commenting on the 'sheer unpredictability and unaccountability of the sounds' [31].

Seemingly, miming is not something that audiences often experience correctly or even concern themselves with.

Shand also likened a performance of 'One Five Nine' to 'glimpsing the future' [32]. Presenting what we envisage the instrument to be capable of in the future *in front of an audience* is our way of re-imagining not only what we want our instrument to be, but how we want our audio-visual gestural performance to be experienced.

Davis claims that 'powerful new technologies are magical... opening up novel and protean spaces of possibility within social reality. They allow humans to impress their dreaming wills upon the stuff of the world, reshaping it... according to the designs of the imagination' [9]. Even when powerful new technologies are capable of removing the mimed elements, mime can still be used in performance settings in order to push the boundaries of what is possible, not only for the performer, but more importantly for the audience—as their personal beliefs of what technology is capable of is questioned and challenged.

## 5. ONE FIVE NINE: THE MIME

The music for 'One Five Nine' was composed and produced entirely within the studio. So when translating this already produced piece into a live audio-visual performance for the *AirSticks*, we decided to utilise a sound-first mapping approach similar to the exercise described in section 3.2. The plan was to remove each individual track from the music, and build an interactive replacement that could be performed on the *AirSticks*, accompanied with a real-time

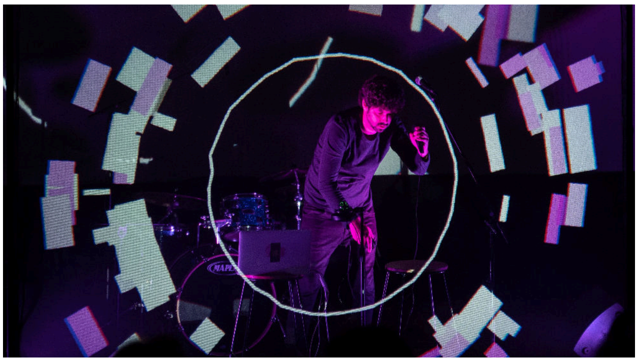

**Figure 3: The original, partly-mimed performance.**

visualisation system.

Again, the process started by simply miming along to the music—keeping in mind what had been proven possible with the *AirSticks* in the past. Every sonic component in the piece was mapped to a physical gesture, and each of these gestures was inspired by imagining how the movement would look if it was being generated by the *AirSticks*.

The first part of the piece is performed on the mallet-percussion style melodic instrument described in section 3.1, visualised with a virtual *Rod*, but the rest of the piece is not suitable for this as it is organised into complex percussive layers. To maintain the complexity of the complete piece, the idea of a looping-system for the *AirSticks* was imagined. As the looping mechanics were mimed, it was once again clear that the experience of watching a mimed performance with the *AirSticks* was identical to watching a non-mimed performance.

Instead of a full coupling between the *AirSticks* and the rest of the system, it was decided to mime this section in front of the audience and see how it felt, take note whether anyone in the audience would comment, and probe into their initial thoughts on the imagined mappings without confessing some of the performance was mimed.

In order to establish the feasibility of the system's mechanics and make sure not to arouse suspicion, the first part of the performance is completely interactive. The piece starts by sampling the performer's voice through a microphone. A clearly communicated button press and the manipulation of this sample through clear gestures inform the audience of the possibilities of taking live sound and transforming it through hand movements. The voice is re-pitched, filtered, panned and put through effects with additional clear gestures.

The visuals are then introduced with an obvious strike that also triggers the first note in the opening five-note mallet-percussion theme. The sound and visuals are both controlled here by the movement of both hands in the most transparent mapping of the piece.

In the next part, an inner *Ring* is introduced that is manipulated in real-time with strikes from either hand (figure 3), followed by an outer ring we call the *Vortex* which visualises a hihat pattern controlled through button presses and various gestures. A button is then pressed that triggers *Ableton Live* to start playing its timeline. Panning, filtering and placement of effects over the backing-track is controlled, but all the rhythmic gestures are mimed as a groove is constructed out of several loops—automatically by *Ableton*. The original piece was modified so that each looped rhythm is 'playable' by the performer. The melody is then reintroduced over the loops, played in real-time, and finally the piece gets deconstructed as the miming turns back to real-time playing of the very same samples—in the hope to alleviate any doubt that the previous groove was performed in real-time.

The following video showcases this combination of controlled and mimed playing:

'One Five Nine—Parts 1 and 2':
`https://youtu.be/msoUOe_LEHk`

We rarely received comment from reviewers or audience members that there was any miming or 'cheating' in this performance. A lack of control over the elements of sound and visuals was never questioned, as can be seen the following review:

> 'Man, body, music, and light as one... He reaffirms his mastery of rhythm by engaging alternating loops that drift into perfect syncopation as he swings his drumsticks into the sky... [He] mesmerize[s] us with his organic flow. A perfect amalgam between man-machine.' [22]

## 6. ONE FIVE NINE: FOR REAL

Our initial performance was conceived using a combination of working technologies and 'Wizard of Oz'-style trickery. The components of 'One Five Nine' that were mimed allowed us to experiment freely with their composition. It liberated the development process by not constraining the movements of the performer to how a fully-functioning technology reacts to their actions. If we were to use a functional audio-visual DMI to develop our piece, the performer would react to the instrument's behaviour, tweak the configuration, and then react to the adjustments. In contrast, developing gestures through miming to a backing-track, and developing graphical interactions with only fake input feeding into the system, allows the designers to be in total control of how the system presents itself. The usual DMI feedback-loop of *(re)action*$\longleftrightarrow$ *interaction* is ignored.

We were able to carefully choreograph what the audience would see, and get their feedback on the workings of the 'instrument' without creating the software that would make it functional.

The performance we have described is a standalone piece that utilised miming as a dramaturgical device—but beyond that, it was the beginning of an experiment in a mapping approach that starts with sound first (outlined fully in figure 4). As much as it has become evident that producing a performance like this is possible without putting in the effort to build a fully-functioning instrument, we *are* in fact instrument designers. The next step in our process after completing this show, was to turn the trickery into reality—to give back full control to the performer. Now that we knew how we wanted the instrument to work—and had presented and iterated upon this prototype in front of audiences—we set out to create the interactive systems that behaved this way.

The piece 'One Five Nine' was focused around three main audio-visual components—the melodic *Rods*, the hihat *Vortex*, and the looper *Ring* Two first two components *were* actually controlled by the *AirSticks*, but what was arguably the main component—*the Ring*—was mimed. *The Ring* is a membrane-like circle that levitates in front of the performer. When it is 'hit' by one of the *AirSticks*, a burst of angular noise appears to emanate from where it was struck, while a similarly noisy percussion sample is sounded. As the audience views it, the performer can strike in different locations around the circumference of the ring to trigger a range of different audio-visual events. In our faked performance, the 'striking' gesture around the ring is introduced, and a beat is apparently played live before the audience. The beat is then

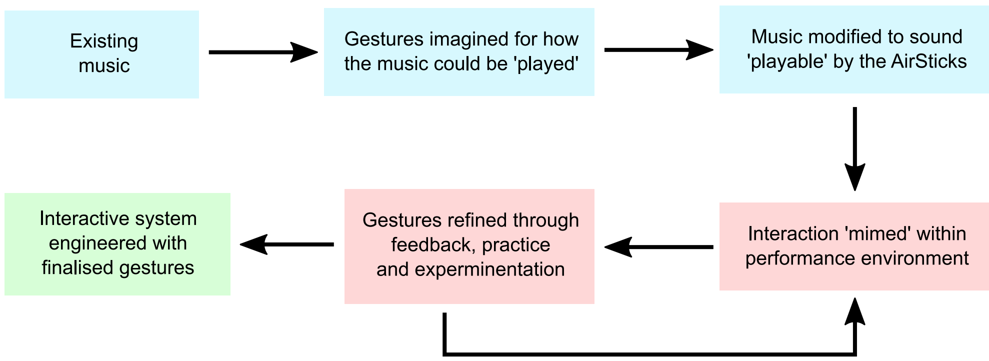


**Figure 4: The sound-first development process of the 'Ring' instrument mapping.**

looped—an action that is implied since most contemporary audience's are familiar with the gesture of looping. In reality, the *Ableton* track controlling the sound and vision just continues to play, but the performer no longer mimes any actions to it. More strikes to the *Ring* are then overdubbed and looped again to create a fully-tracked drum pattern.

From this description, we can see that there were two faculties we needed to program in order to bring to life a functional version of the *Ring*: the striking mechanism, and the looping mechanism.

To create the striking system, five hit-boxes for the *AirSticks* are placed in space around the ring, with each set to trigger the start of a sound and animation. The original piece layed out seven fake hit-boxes to trigger—due to the fact that the music had seven samples making up the beat. We found though that limiting the number to five allowed for easier and more consistent performance with the *AirSticks*.

A gesture that found its way into the original show was one of twisting the arm and shoulder after a strike had been performed—in order to give physicality to a filtering effect applied to the sounds. This gesture—and others like it—were introduced into the performance as subtle nuances of action. But since the accuracy of the performance as a mime was not reliant on the need to perform the exact same motion each time, these gestures like the twisting morphed show-to-show from subtle to increasingly pronounced. With each performance, a confidence and flair developed in the gestures—not dissimilar to a dancer becoming more comfortable with their choreography and perhaps experimenting with it.

With all the dimensions of input available to us when creating the fully-functioning *Ring*, we could implant these mimed gestures into the actual workings of the instrument. After one of the ring's hit-boxes has been struck, a twist of the *AirSticks* now contracts the ring and pulls it in towards the strike point. The effect remains active until the user moves their hand away from the ring (causing a 'note-off'). As the sound and graphics are now highly integrated into the twist motion, any user playing on the *Ring* is encouraged to create this gesture for themselves.

To create the looping mechanic, buttons on the *AirSticks* were assigned to the functions of starting, stopping, and deleting a recording. The loop length can be set in the software, and once the track reaches the end of the loop, a user can overdub whilst the record function is enabled. As mentioned before, looping is quite a standardised feature in live contemporary music performances, which means we can assume the audience understands this mechanism without making it overtly physical. As abstract as the concept is, audiences routinely witness performer's disembodied sounds looping as they overdub new layers. Some performers make the looping gesture obvious, perhaps with an emphasised kick of a foot-pedal, but as the notion has become ingrained in the mainstream performance vocabulary, the need for such efforts to stifle confusion are less necessary. This was the thought around how we presented the looping rhythms in our original show.

The audience may not need the looping mechanism to be transparent in its function, but when played for real it *is* necessary for this operation to be transparent to the user. To indicate when the system is in overdub mode, a press of the same 'record' button on the *AirSticks* activates a neon-red glow around the *Ring*. When the record mode is switched off, the *Ring* returns to its regular appearance to indicate no overdub will occur.

The *Ring* is now a fully featured gestural synthesizer and looper. After accomplishing this, we re-integrated the ring into the 'One Five Nine' scene, and alongside the two other components that were *not* originally mimed, this environment is no longer a slave to an existing track. Instead, it is an environment where the user can perform and compose as they please. A new, completely interactive piece was developed to demonstrate this new environment—now a fully featured audio-visual 'instrument'. The demonstration was presented at the 2019 Guthman Musical Instrument Competition in Georgia Tech in Atlanta, Georgia, where it took out the Audience Choice Awards for Best Instrument and Best Performance. A similar presentation was recently made at SIGGRAPH Asia's 2019 Real-Time Live Competition, in which the *AirSticks* took out the judge's award for Best Presentation.

A video of this demonstration can be seen here:
`https://youtu.be/KAasdjohfuo`.

## 7. CONCLUSION

Developing mappings for DMIs that are intuitive for a performer as well as convincing for their audience is not easy. This paper has outlined two processes that designers can use to achieve these goals—movement-first and sound-first mapping. We have employed both techniques to construct mappings for our gestural audio-visual performances, and conclude that success in these mappings is in part due to acknowledging the real-world context of performance DMIs is one involving spectators. Movement-first mappings that take their inspiration from existing gestures and real-life metaphors play to the audience's tacit knowledge of musical performance, and sound-first mapping approaches encourage the designer to decide on gestures based on intuition—emphasising the look of a movement before engineering its interactivity.

We argue that the mapping design process for a performative instrument should extend into its performance context, and encourage designers to exploit their audience's belief systems in order to further the exploration of their instruments. By deciding to mime instead of constructing our interactive systems at the start of development, we were able to focus on the perceived experience of a mapping, easily decide upon and test different mapping strategies without affecting performance quality, and overall, end up with a more cohesive, convincing and imaginative instrument.

## 8. ACKNOWLEDGMENTS

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## 9. REFERENCES

[1] R. Aimi. Percussion instruments using realtime convolution: Physical controllers. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*, pages 154–159, 2007.

[2] F. Calegario, M. M. Wanderley, S. Huot, G. Cabral, and G. Ramalho. A method and toolkit for digital musical instruments: generating ideas and prototypes. *IEEE MultiMedia*, 24(1):63–71, 2017.

[3] B. Caramiaux, A. Altavilla, S. G. Pobiner, and A. Tanaka. Form follows sound: Designing interactions from sonic memories. *Conference on Human Factors in Computing Systems*, 2015-April(March):3943–3952, 2015.

[4] B. Caramiaux, M. M. Wanderley, and F. Bevilacqua. Segmenting and parsing instrumentalists' gestures. *Journal of New Music Research*, 41(1):13–29, 2012.

[5] K. Cascone. Laptop music—counterfeiting aura in the age of infinite reproduction. *Parachute*, pages 52–59, 2002.

[6] K. Chuchacz, S. O'Modhrain, and R. Woods. Physical models and musical controllers: designing a novel electronic percussion instrument. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*, pages 37–40, 2007.

[7] P. Cook. 2001: Principles for designing computer music controllers. In *A NIME Reader*, pages 1–13. Springer, 2017.

[8] R. B. Dannenberg. Music representation issues, techniques, and systems. *Computer Music Journal*, 17(3):20–30, 1993.

[9] E. Davis. *Techgnosis: myth, magic & mysticism in the age of information*. North Atlantic Books, 2015.

[10] C. Dobrian and D. Koppelman. The E in NIME: Musical expression with new computer interfaces. *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 277–282, 2006.

[11] K. Emerson, V. Williamson, and R. Wilkinson. Seeing the music in their hands: How conductors' depictions shape the music. In *Proceedings of the 25th Anniversary Conference of the European Society for the Cognitive Sciences of Music*, volume 31, 2017.

[12] S. Fels. Designing for intimacy: Creating new interfaces for musical expression. *Proceedings of the IEEE*, 92(4):672–685, 2004.

[13] S. Fels, A. Gadd, and A. Mulder. Mapping transparency through metaphor: towards more expressive musical instruments. *Organised Sound*, 7(2):109–126, 2002.

[14] R. Fiebrink, P. R. Cook, and D. Trueman. Play-along mapping of musical controllers. *Proceedings of the 2009 International Computer Music Conference*, pages 61–64, 2009.

[15] R. Fiebrink, D. Trueman, N. C. Britt, M. Nagai, K. Kaczmarek, M. Early, M. Daniel, A. Hege, and P. R. Cook. Toward understanding human-computer interaction in composing the instrument. In *ICMC*, 2010.

[16] J. Françoise and F. Bevilacqua. Motion-sound mapping through interaction: An approach to user-centered design of auditory feedback using machine learning. *ACM Transactions on Interactive Intelligent Systems*, 8(2), 2018.

[17] J. C. Godinho. Miming to recorded music: Multimodality and education. *Psychomusicology: Music, Mind, and Brain*, 26(2):189–195, 2016.

[18] C. Hope and J. C. Ryan. *Digital Arts: An Introduction to New Media*. Bloomsbury Publishing USA, 2014.

[19] A. Hunt, M. M. Wanderley, and M. Paradis. The importance of parameter mapping in electronic instrument design. *Journal of New Music Research*, 32(4):429–440, 2003.

[20] F. Iazzetta. Meaning in musical gesture. *Trends in Gestural Control of Music*, pages 259–268, 2000.

[21] A. Ilsar. *The AirSticks: A New Instrument for Live Electronic Percussion Within an Ensemble*. Phd thesis, University of Technology Sydney, 2018.

[22] R. Llauro. EXTENDED PLAY @ City Recital Hall, NSW (Live Review) 25/08/2018. *Amnplify*, 2018.

[23] P. J. Maes, M. Leman, M. Lesaffre, M. Demey, and D. Moelants. From expressive gesture to sound: The development of an embodied mapping trajectory inside a musical interface. *Journal on Multimodal User Interfaces*, 3(1):67–78, 2010.

[24] T. Magnusson. Designing constraints: Composing and performing with digital musical systems. *Computer Music Journal*, 34(4):62–73, 2010.

[25] T. Magnusson and E. H. Mendieta. The acoustic, the digital and the body: A survey on musical instruments. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*, pages 94–99. ACM, 2007.

[26] T. Mitchell. SoundGrasp: A gestural interface for the performance of live music. *International Conference on New Interfaces for Musical Expression*, 2011, Oslo, 2011.

[27] S. C. Nanayakkara, E. Taylor, L. Wyse, and S. Ong. Towards building an experiential music visualizer. In *2007 6th International Conference on Information, Communications & Signal Processing*, pages 1–5. IEEE, 2007.

[28] T. Nunn. Electroacoustic percussion boards: sculptured musical instruments for improvisation. *Leonardo*, 21(3):261–265, 1988.

[29] K. Nymoen, R. I. Godøy, A. R. Jensenius, and J. Torresen. Analyzing correspondence between sound objects and body motion. *ACM Transactions on Applied Perception*, 10(2), 2013.

[30] B. Ostertag. Human bodies, computer music. *Leonardo Music Journal*, pages 11–14, 2002.

[31] J. Shand. Ellen Kirkwood review: China Mieville's weird work looms large in music. *The Sydney Morning Herald*, nov 2015.

[32] J. Shand. Alon Ilsar/Hinterlandt review: Acoustic surprises precede glimpse of future. *The Sydney Morning Herald*, feb 2019.